

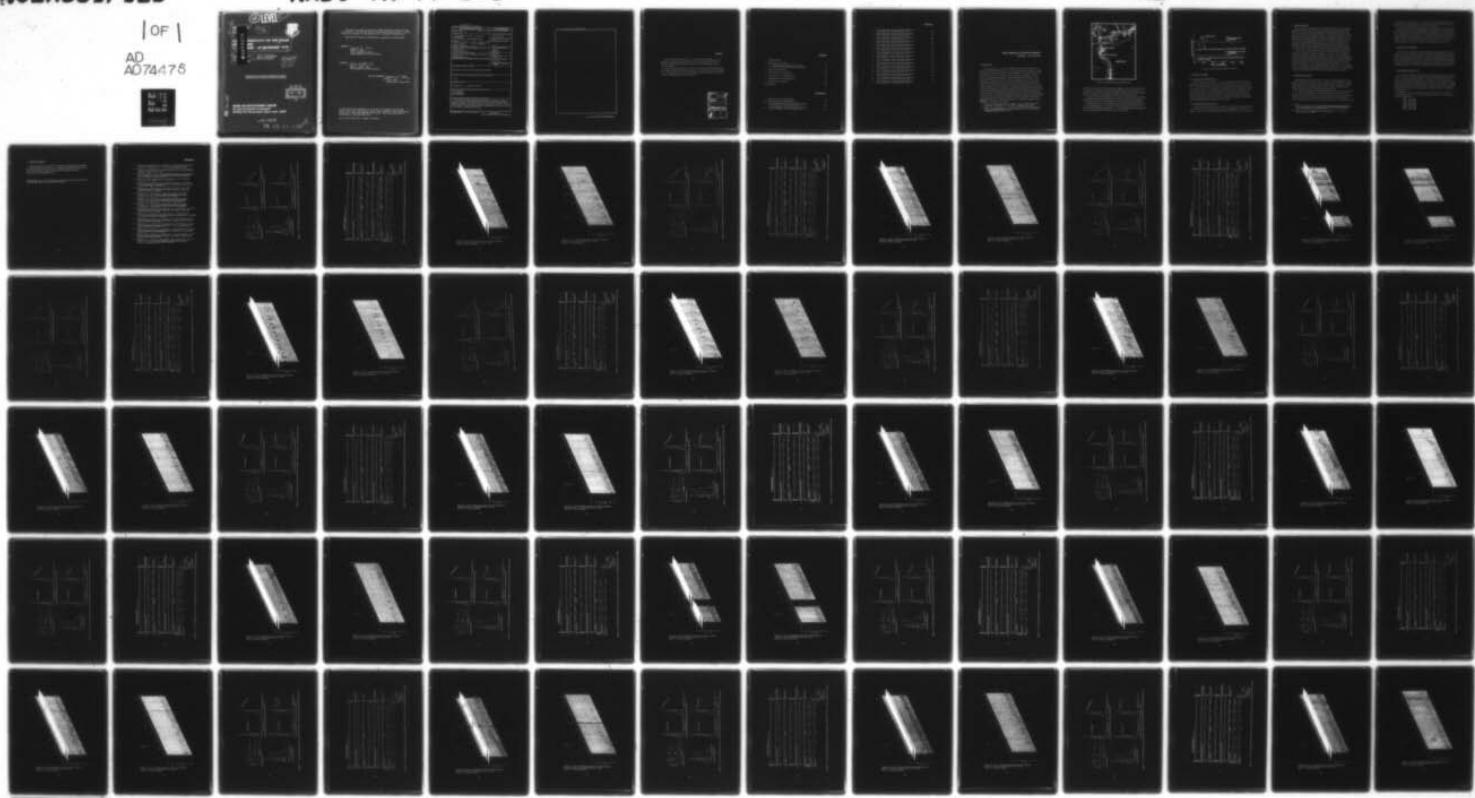
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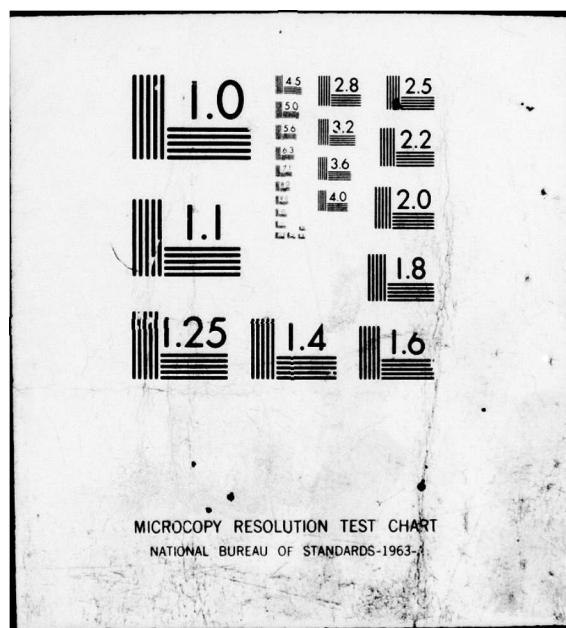
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RADC-TR-79-178 has been reviewed and is approved for publication.

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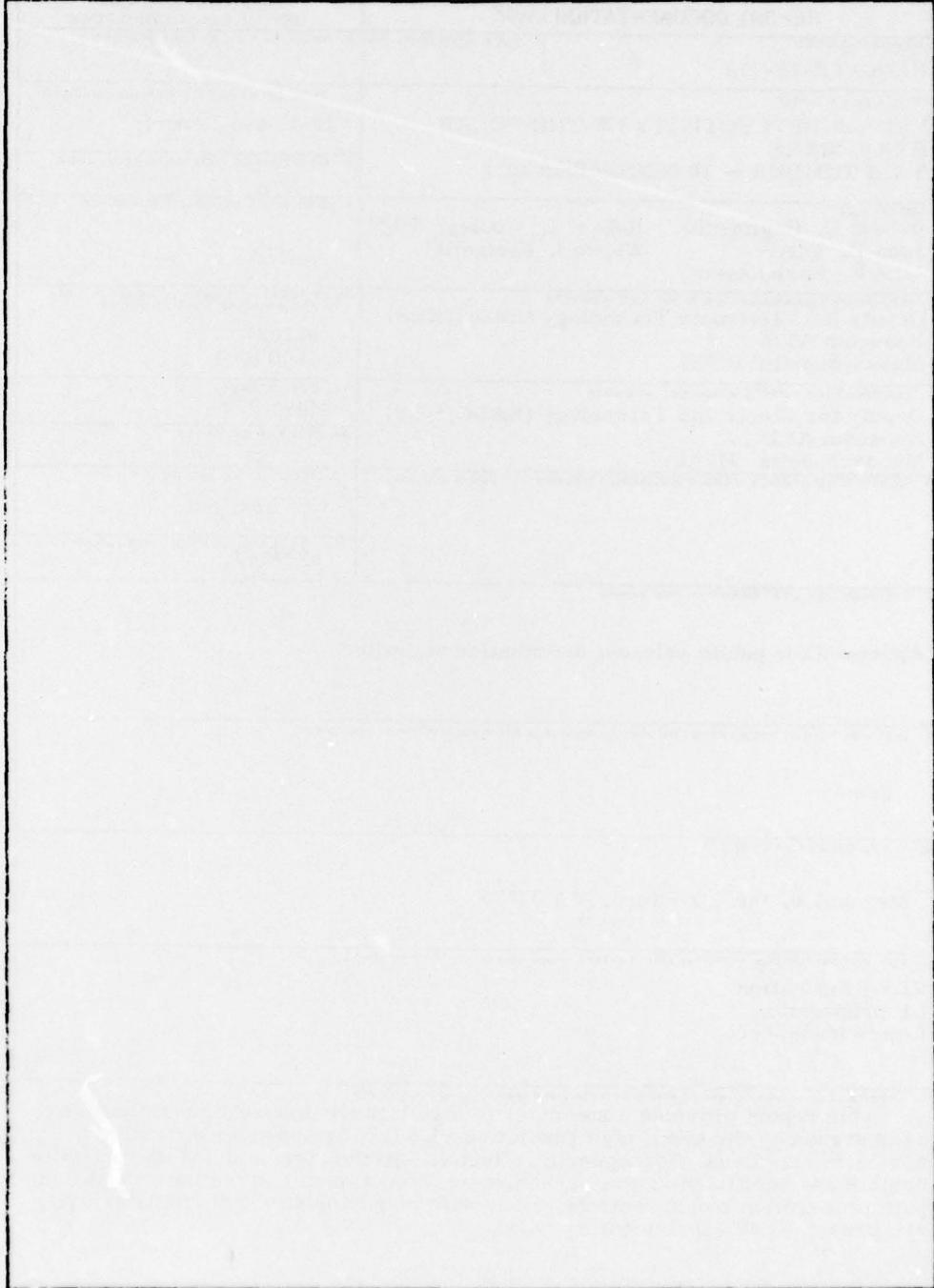
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## Preface

The authors thank in particular Mr. Duane Marshall of Megapulse, Inc., for help with the equipment that made the measurements possible, and Mr. Bjarne Ebbesen of the Danish Meteorological Institute for the outstanding operation at Qanaq, Greenland.

Appreciation is also extended to the Danish Commission for Scientific Research in Greenland for allowing these measurements to be conducted and to Jorgen Taagholt and V. Neble Jensen of the Danish Meteorological Institute's Ionospheric Laboratory for their continued cooperation in this program.

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## VLF/LF Reflectivity of the Polar Ionosphere

3 September - 30 December 1978

### 1. INTRODUCTION

This report provides a summary of high latitude ionospheric reflectivity, as observed by the USAF's high resolution VLF/LF ionosounder operating in northern Greenland.<sup>1,2</sup> As shown in Figure 1, the transmitter is located at Thule Air Base, Greenland (76° 33'N. Lat., 68° 40'W. Long.), and the receiving site is 106 km north at the Danish Meteorological Institute's Ionospheric Observatory in Qanaq, Greenland (77° 24'N. Lat., 69° 20'W. Long., Geomagnetic Lat. 89° 06'N). The ionosounding transmissions consist of a series of extremely short (approximately 100  $\mu$  sec) VLF pulses, precisely controlled in time, and radiated from a 130-m vertical antenna. At the receiving site, orthogonal loop antennas are used to separate the two polarization components of the ionospherically reflected skywave signal. One antenna oriented in the plane of propagation, is used to sense the groundwave and the "parallel" component of the downcoming skywave. The second loop, nulled on the groundwave, senses the "perpendicular" skywave component. The signal from each of the antennas is digitally averaged to improve the signal-to-noise ratio of the individual received waveforms before they are recorded on magnetic tape. An

(Received for publication 4 June 1979)

1. Lewis, E.A., Rasmussen, J.E., and Kossey, P.A. (1973) Measurements of ionospheric reflectivity from 6 to 35 kHz, J. Geophys. Res. 78:19.
2. Kossey, P.A., Rasmussen, J.E., and Lewis, E.A. (1974) VLF pulse ionosounder measurements of the reflection properties of the lower ionosphere, Akademie Verlag, COSPAR, July.

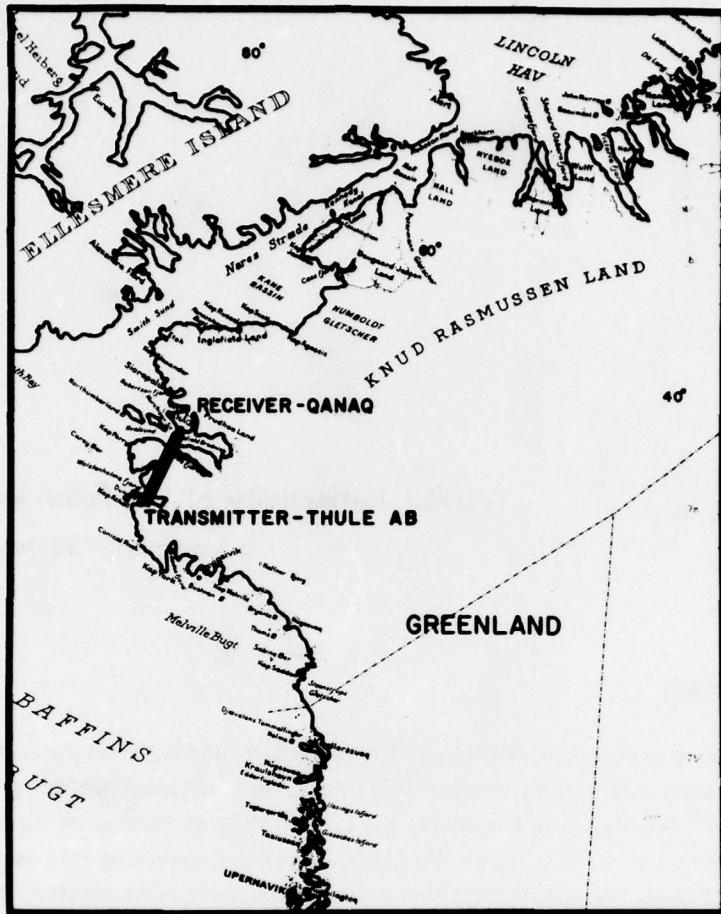


Figure 1. Geometry of the Propagation Path

example of the observed waveforms is given in Figure 2, where the "parallel" waveform (Figure 2a) consists of a groundwave propagated pulse, a quiet interval containing low level, off path groundwave reflections, followed by the first-hop parallel skywave component. The perpendicular waveform is shown in Figure 2b.

Ionospheric reflection parameters are derived by computer (AFGL's CDC 6600) processing of the ground and ionospherically reflected waveforms with allowance made for factors such as ground conductivity and antenna patterns (see Section 4).

Although the data are recorded about once per minute, for this report the waveforms are averaged into 2-hr time blocks with the exception of the three-dimensional waveform presentations (Section 2.2). The resulting information is presented in a weekly format (Figures 3 through 19 as described below).

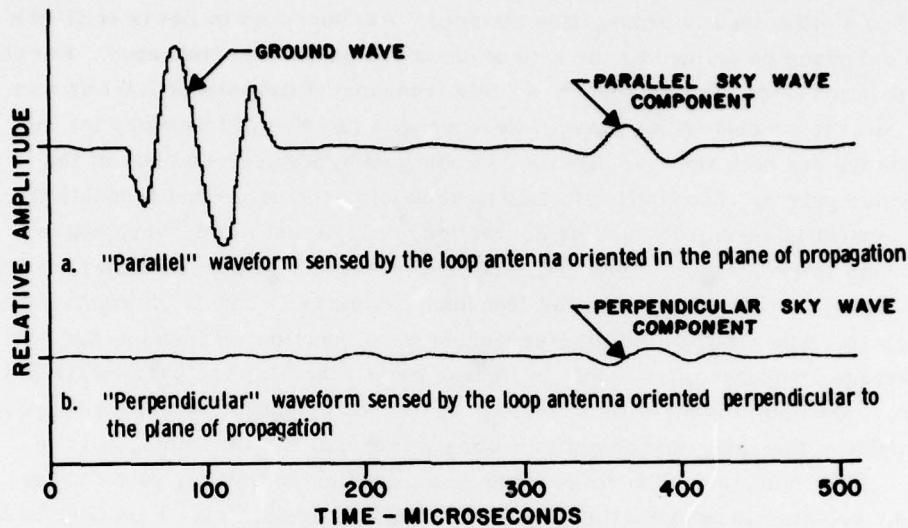


Figure 2. Example of the Observed Waveforms

## 2. OBSERVED WAVEFORMS

### 2.1 Weekly Example of Individual Waveforms

In part A of Figures 3 through 19, a set of averaged parallel and perpendicular waveforms is presented for the time block centered near local noon of the indicated day. Each of these waveforms is comprised of 256 digitally averaged points spaced  $2 \mu$  sec apart. In part B of the figures, the groundwave Fourier amplitudes are shown as a function of frequency. Although the data presented in parts C through L of the figures are generally limited to frequencies in the first, or principal, lobe of the spectrum, information at higher frequencies can be used when sufficient signal-to-noise conditions exist. There is, however, a frequency range around each spectral null where insufficient signal exists for measurements.

### 2.2 Three-Dimensional Waveform Presentation

A three-dimensional display of the recorded  $\parallel$  waveforms covering each weekly period is shown in Part R of each figure and the corresponding  $\perp$  waveforms are shown in Part S. For these plots the data has been averaged into 15-min time blocks.

### 3. REFLECTION HEIGHTS

The group mirror height (GMH) of reflection was obtained by determining the group delay of the skywave relative to the groundwave and attributing the time difference, by simple geometry (assuming a sharply bounded mirror-like ionosphere) to a difference in propagation distance. As discussed in Lewis et al<sup>1</sup> the group delay can be defined as the rate of change of phase with frequency. For the GMH data presented in this report, a finite frequency difference of 1.0 kHz was used, and the corresponding phase difference as a function of frequency for the groundwave and both skywave signals was obtained by Fourier analysis of the respective pulses. The GMH calculations took into account ground conductivity ( $10^{-3}$  mho/m is assumed), and the corrections of Wait and Howe<sup>3</sup> were applied.

Group mirror heights obtained from the parallel and perpendicular waveforms are plotted as a function of frequency in parts C and D of Figures 3 through 19. The GMH's are also presented as a function of time-of-day for the average frequency of 16.5 kHz in figures parts E and I. The parallel GMH's in part E are shown along with an average reflection height for reference purposes. Each point of the reference height is a weekly average, by time block, for the 7-day period indicated. The corresponding perpendicular GMH's, part I of the figures, are also shown with the weekly average for comparison. Part G gives the average, by time block, for the daily parallel GMH data of part E, and part K gives the corresponding perpendicular GMH averages from the daily data of part I.

### 4. REFLECTION COEFFICIENTS

Assuming that the ionosphere acts as a "mirror" at the GMH, plane wave reflection coefficients<sup>4</sup> were obtained by comparing the ratio of the skywave Fourier amplitude at a specific frequency to that of the groundwave, taking into account the antenna patterns, wave spreading, earth curvature, ground conductivity, path lengths, and antenna patterns including ground image effects.

The reflection coefficient  $\| R \|$  was obtained from analysis of the parallel skywave component and is plotted as a function of frequency in part C of Figures 3 through 19. The  $\| R \|$  coefficient for 16 kHz is plotted as a function of time-of-day in part F along with the average of the indicated week for reference purposes. From the perpendicular skywave pulse, the coefficient  $\| R \perp \|$  was obtained and appears

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3. Wait, J. R., and Howe, H. H. (1956) Amplitude and Phase Curves for Ground-Wave Propagation in the Band 200 Cycles per Second to 500 Kilocycles, Nat. Bur. Stand. U. S. Circ. No. 574.
4. Budden, K. G. (1961) Radio Waves in the Ionosphere, p. 85, Cambridge University Press, London.

as a function of frequency in part D. The 16 kHz  $\| R \perp$  is shown along with its reference in part J. Parts H and L present the average, by time block, of the daily  $\| R \|$  and  $\| R \perp$  data presented in parts F and J, respectively.

For certain coefficient data points, plotted as asterisks (\*), the reflection coefficient appears without a corresponding GMH. For these particular data, only the skywave-groundwave ratios could be obtained as the skywaves were too weak to provide reliable group delay information. The reflection coefficients were therefore estimated using a nominal GMH of 80 km in the calculations. These estimated coefficient values are included in the averages presented in parts H and L, but the assumed heights are not used in the GMH averages shown in parts G and K.

## 5. SUPPLEMENTARY INFORMATION

For purposes of comparison and interpretation, certain supplementary data are presented. Part M of the figures shows the magnitude of the horizontal component of the polar magnetic field as recorded on a three-axis fluxgate magnetometer and part N presents 30-MHz riometer data, an indicator of D-region particle precipitation. These supplementary data were recorded at 30-sec intervals by RADC/EEP at Thule AB; the curves represent the average of 10-min periods. The solar zenith angle is given in part O of Figures 3 through 19 for the indicated mid-week date.

## 6. IONOSPHERIC DISTURBANCE DATA

Solar activity continued at an enhanced level through the period covered by this report. The most outstanding energetic particle event during this period began on 23 Sep (DAY 266) and lasted until about 1 Oct (DAY 274). The 30 MHz riometer showed 10 dB absorption on 24 Sep (DAY 267) and the VLF/LF ionosounder records indicated that the reflection heights dropped to as low as 50 km. This is the strongest event, producing the greatest dB riometer absorption and the lowest ionospheric reflection height, to have occurred since the beginning of the polar ionosounding program in 1974.

Eight other events occurred during this report period; however, none was strong enough to produce more than 1 dB riometer absorption. The dates for these events are listed below.

8 Sep	(DAY 251)
2 Oct	(DAY 275)
9 Oct	(DAY 282)
12 Oct	(DAY 285)
4 Nov	(DAY 308)
10 Nov	(DAY 314)
28 Nov	(DAY 332)
12 Dec	(DAY 346)

## 7. ADDITIONAL COMMENTS

This report is one of a series.<sup>5-16</sup> Comments and suggestions for improving its usefulness should be addressed to the Propagation Branch (EEP), Electromagnetic Sciences Division, Deputy for Electronic Technology (RADC/EEP), Hanscom AFB, Massachusetts 01731.

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(Because of the large number of references cited above they will not be listed here. See Reference Page 13, for References 5 through 16).

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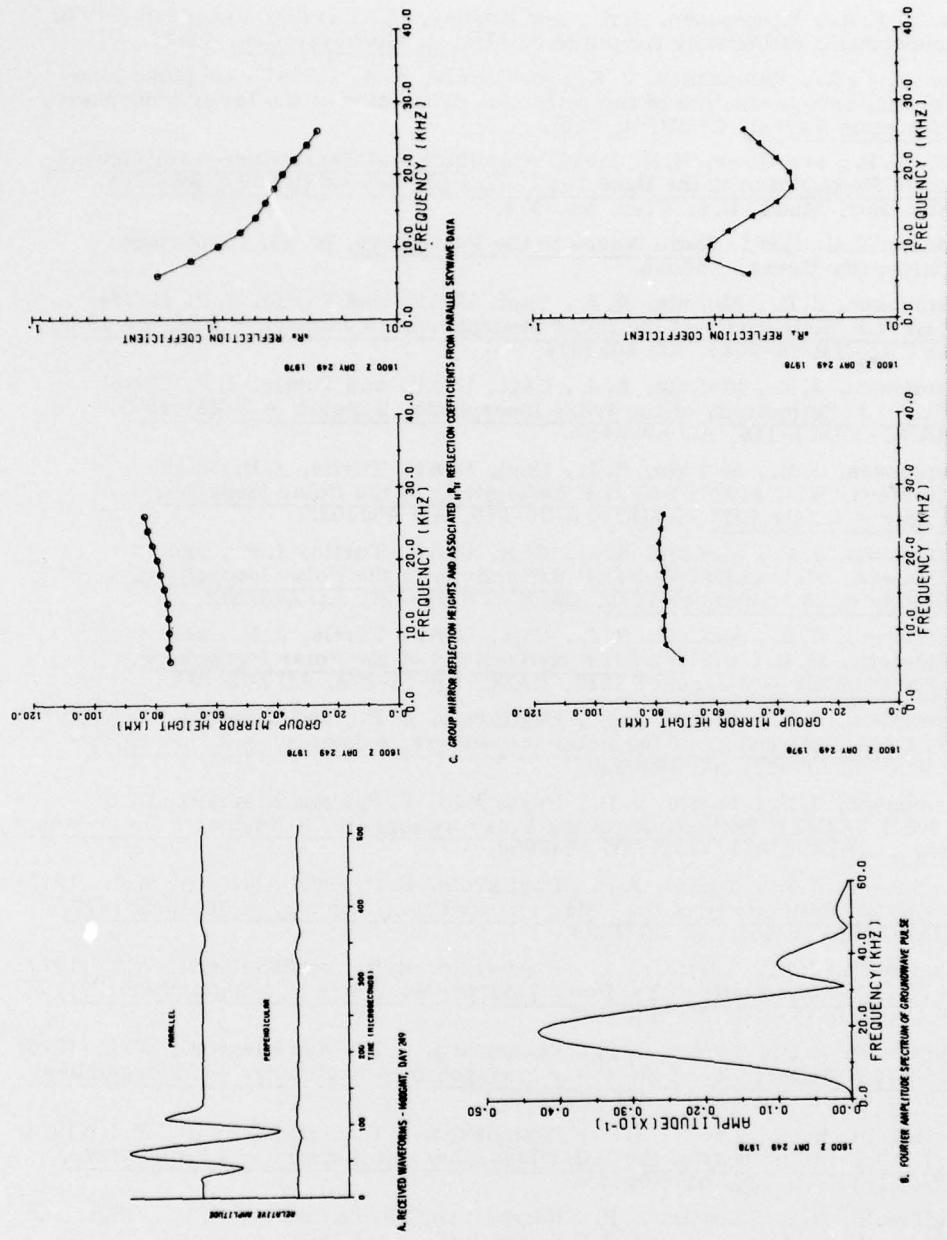


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 246 (3 Sep) — DAY 252 (9 Sep) 1978

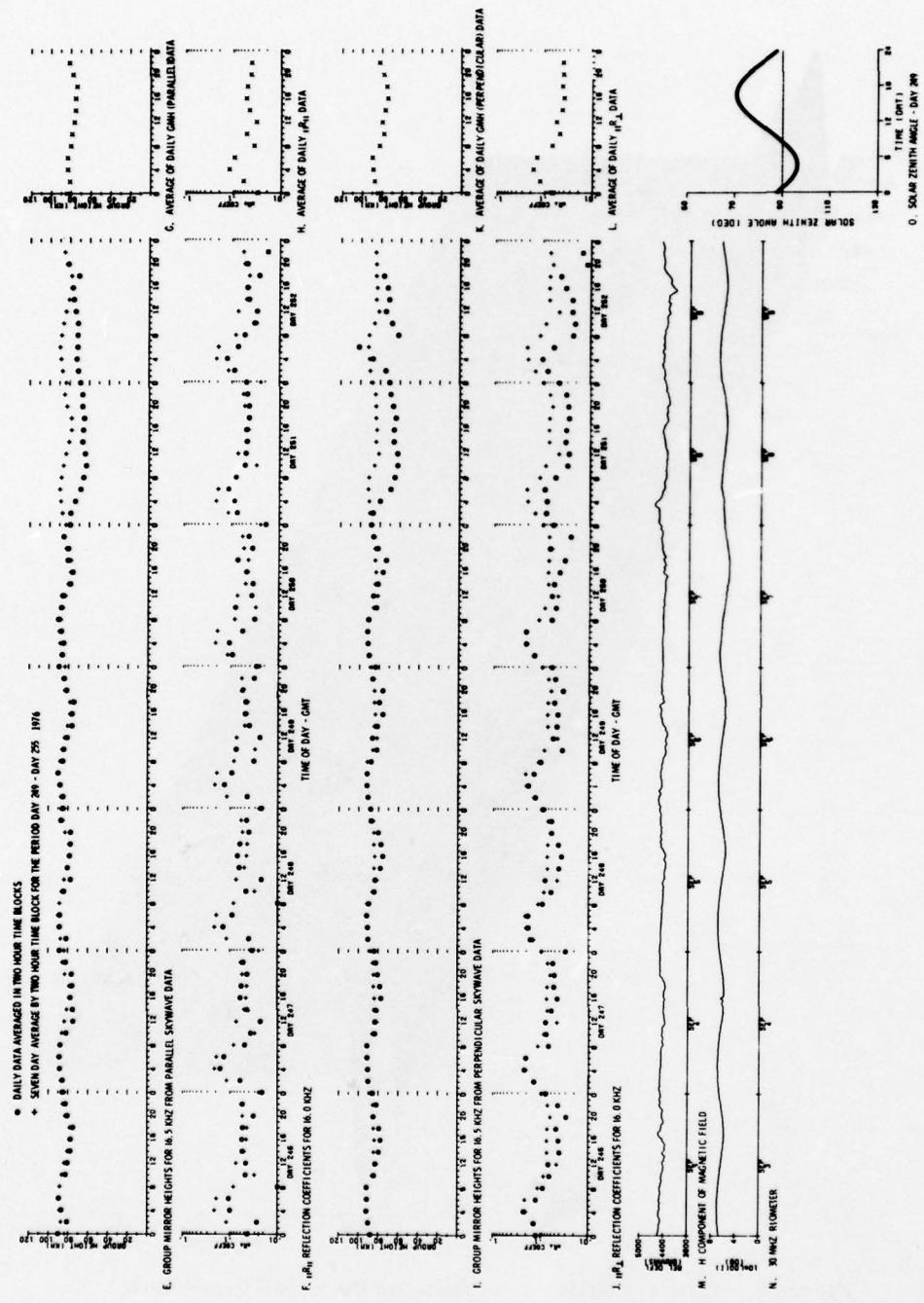


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 246 (3 Sep) - DAY 252 (9 Sep) 1978 (Cont)

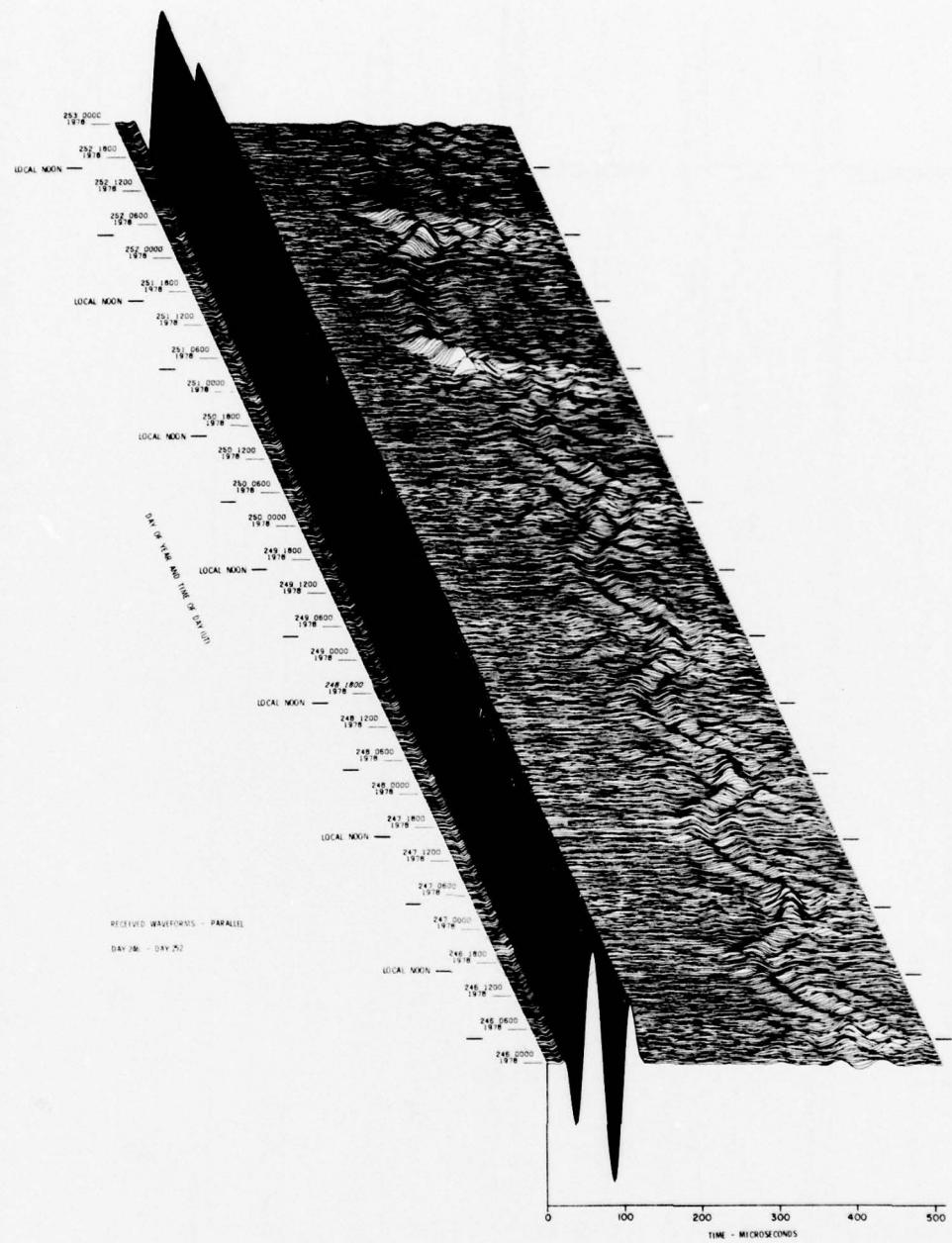


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere,  
DAY 246 (3 Sep) - DAY 252 (9 Sep) 1978 (Cont)  
Part R. II Waveform Display

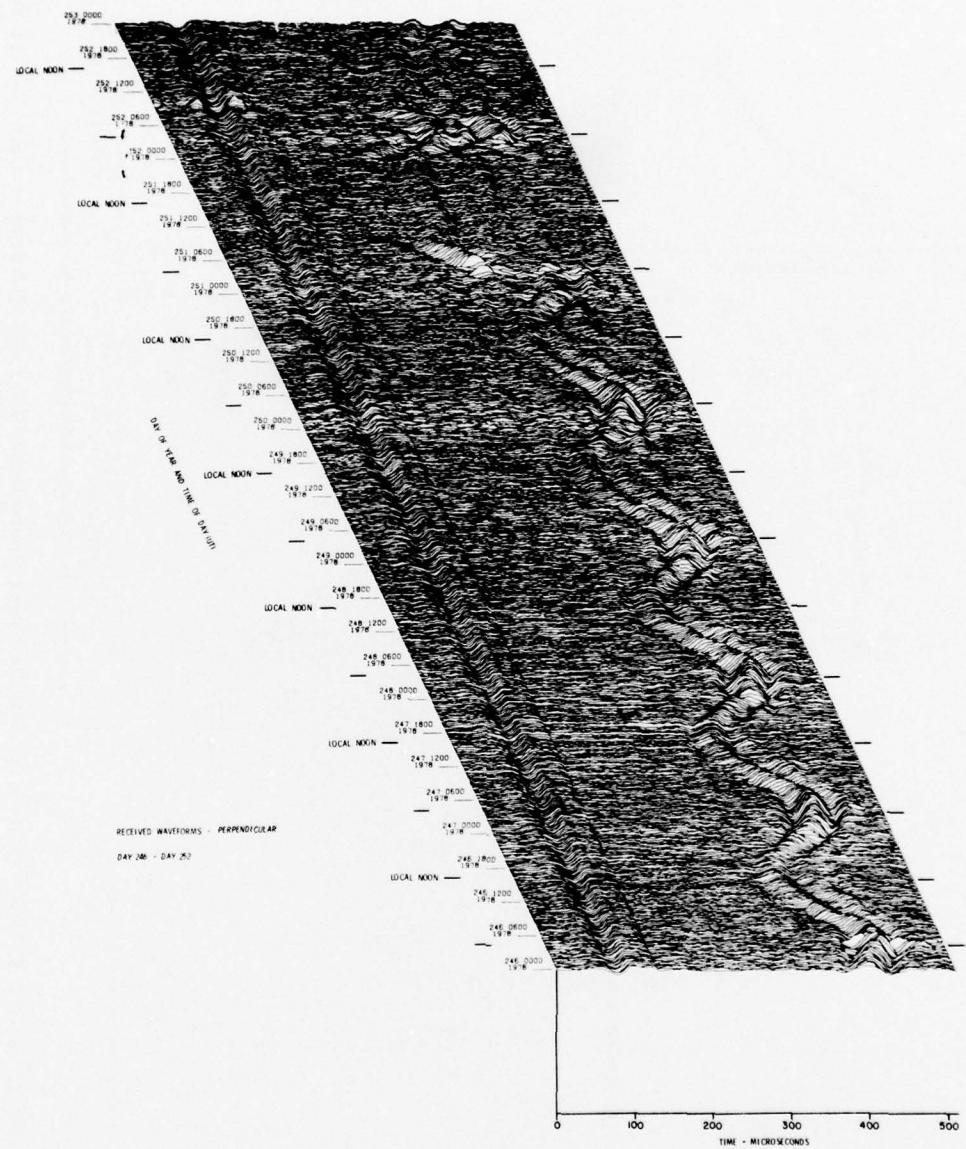


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 246 (3 Sep) - DAY 252 (9 Sep) 1978 (Cont)  
 Part S.  $\perp$  Waveform Display

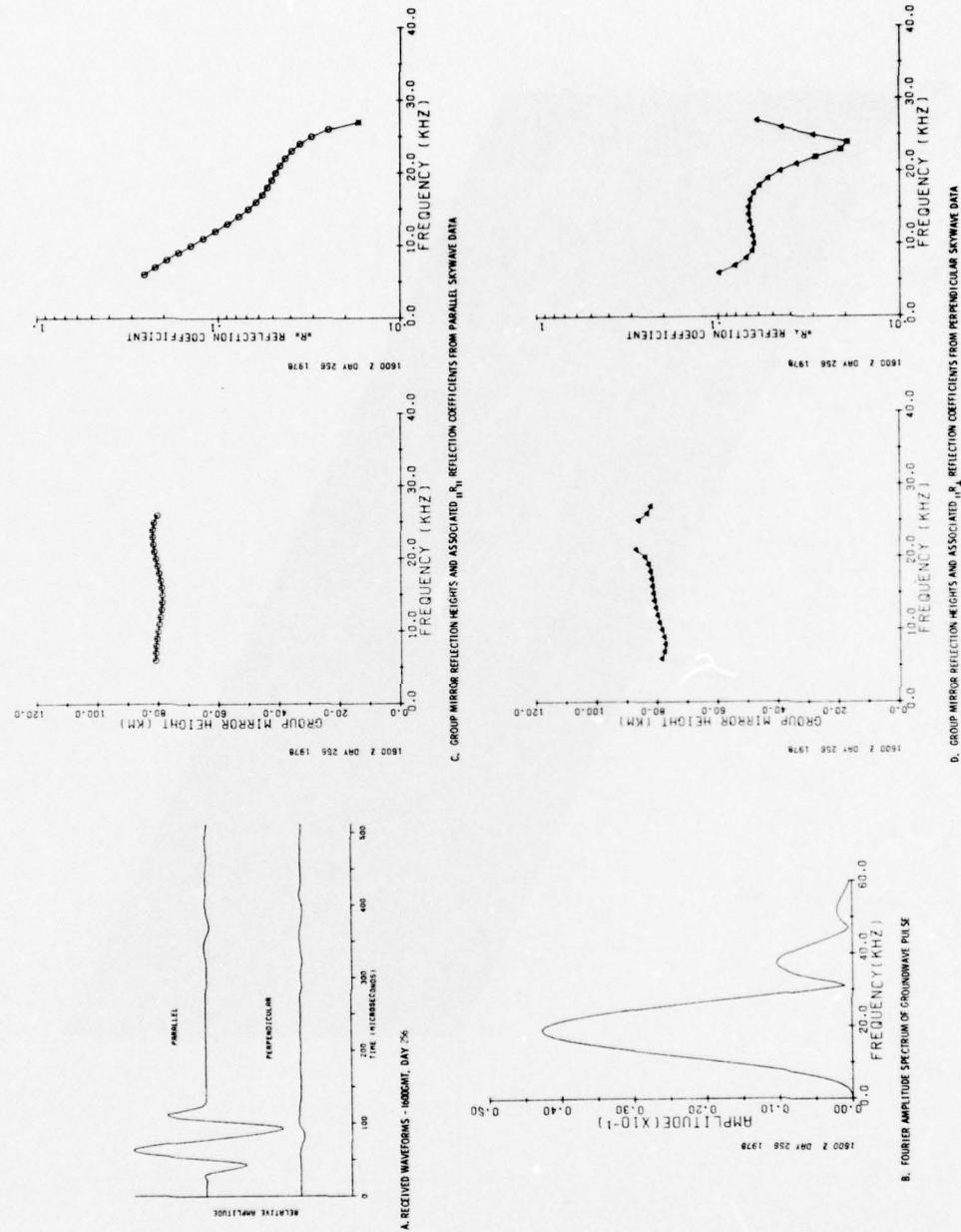


Figure 4. VL/F/LF Reflectivity Data for the Polar Ionosphere, DAY 253 (10 Sep) - DAY 259 (16 Sep) 1978

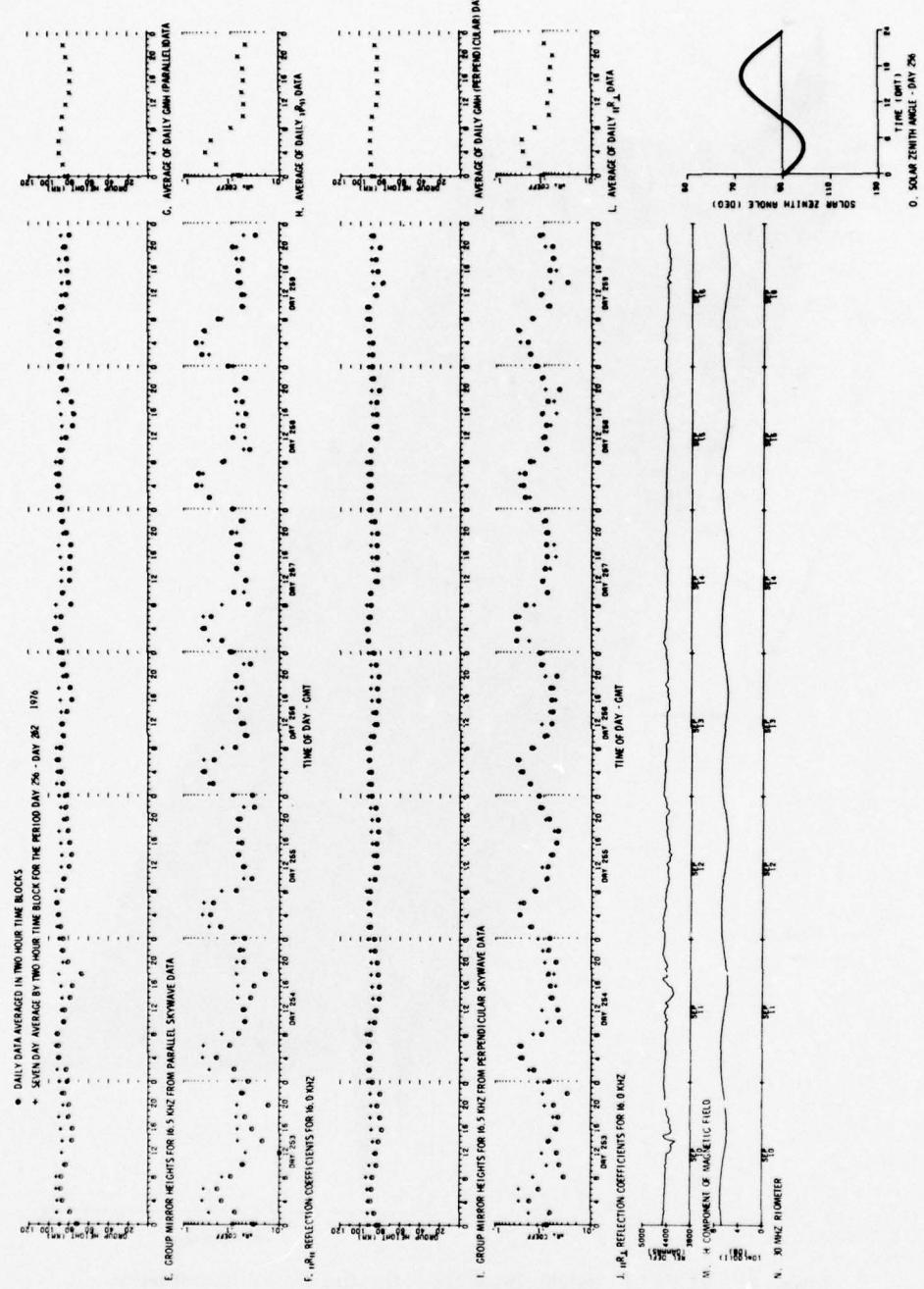


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 253 (10 Sep) – DAY 259 (16 Sep) 1978 (Cont)

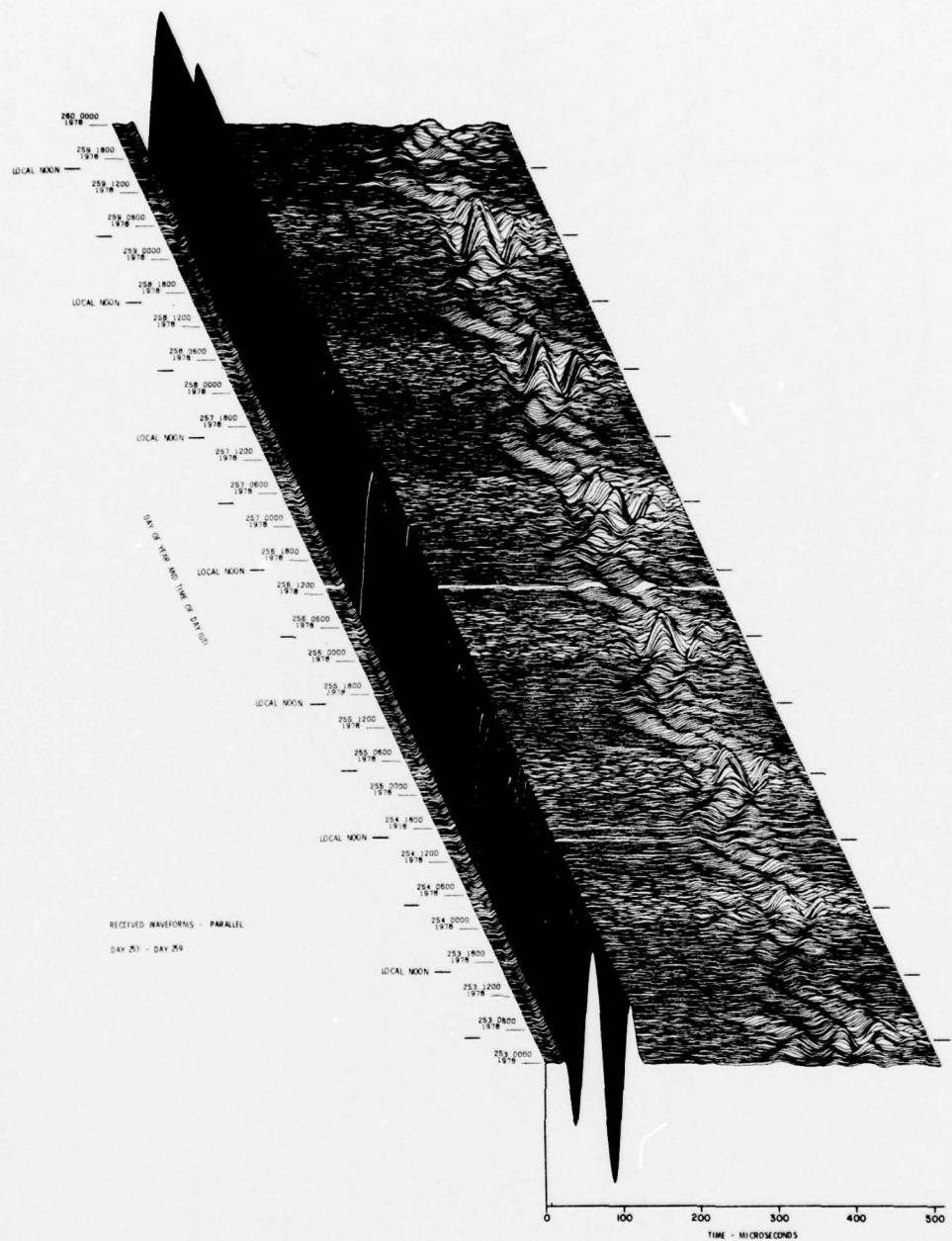


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere,  
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 Part R.  $\parallel$  Waveform Display

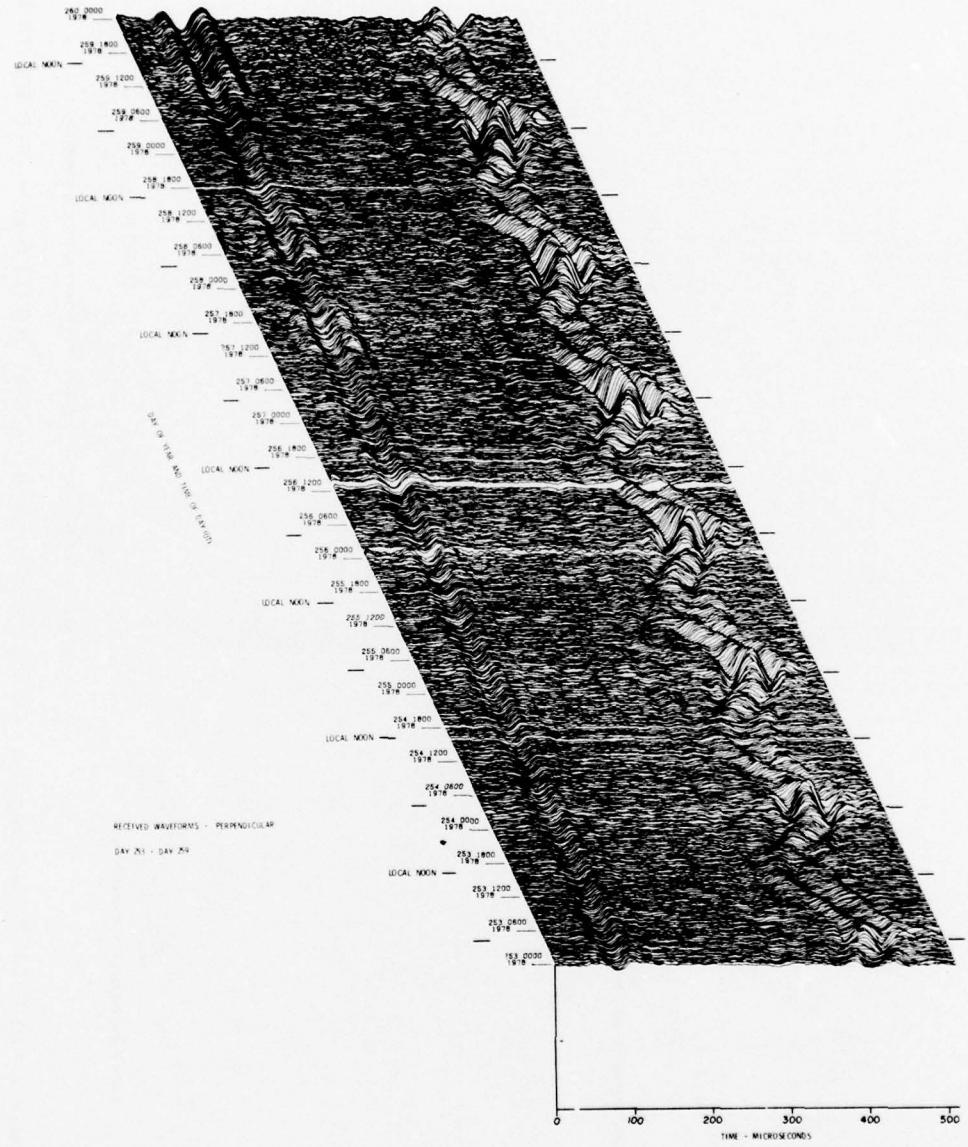


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere,  
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 Part S.  $\perp$  Waveform Display

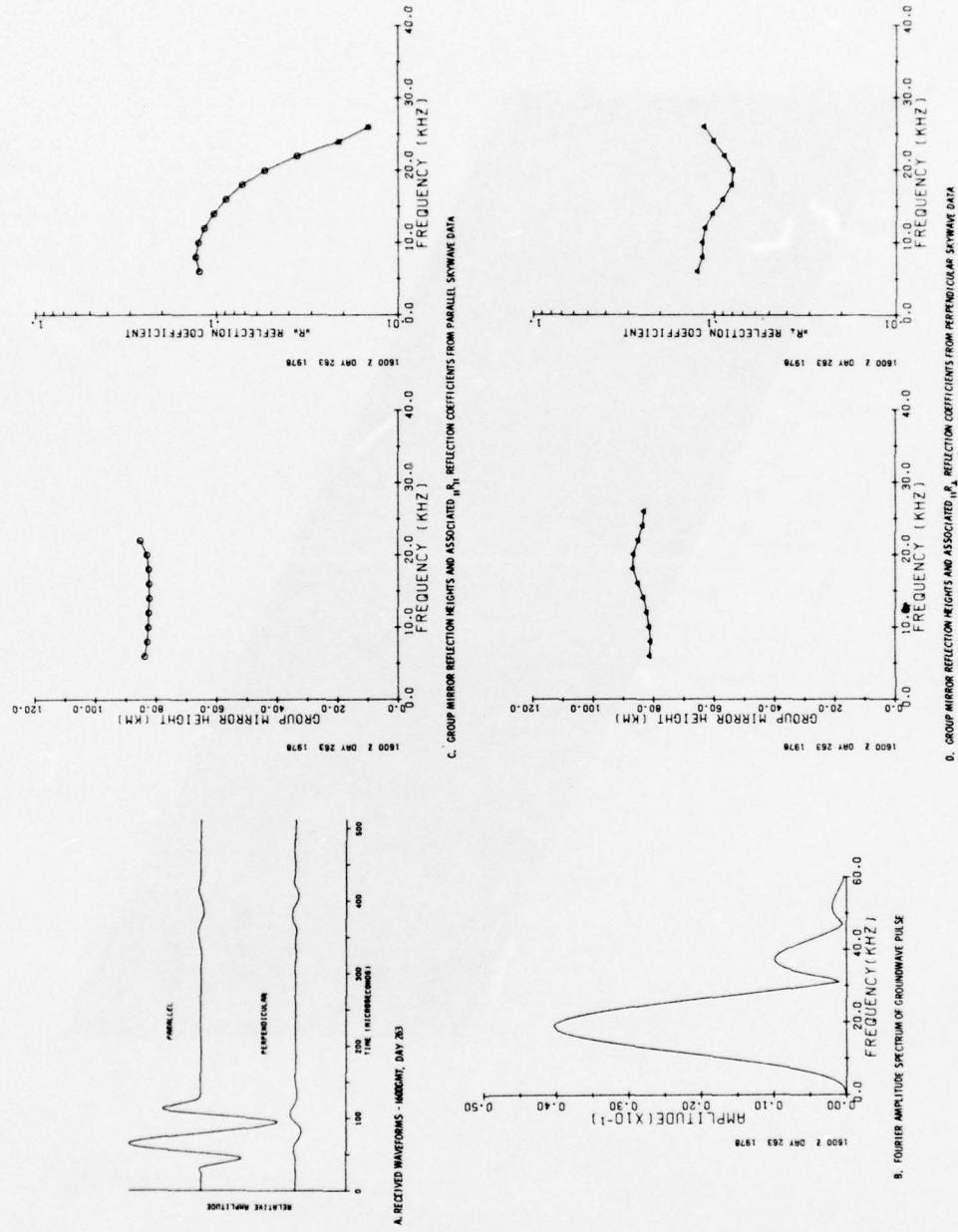


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 260 (17 Sep) – DAY 266 (23 Sep) 1978

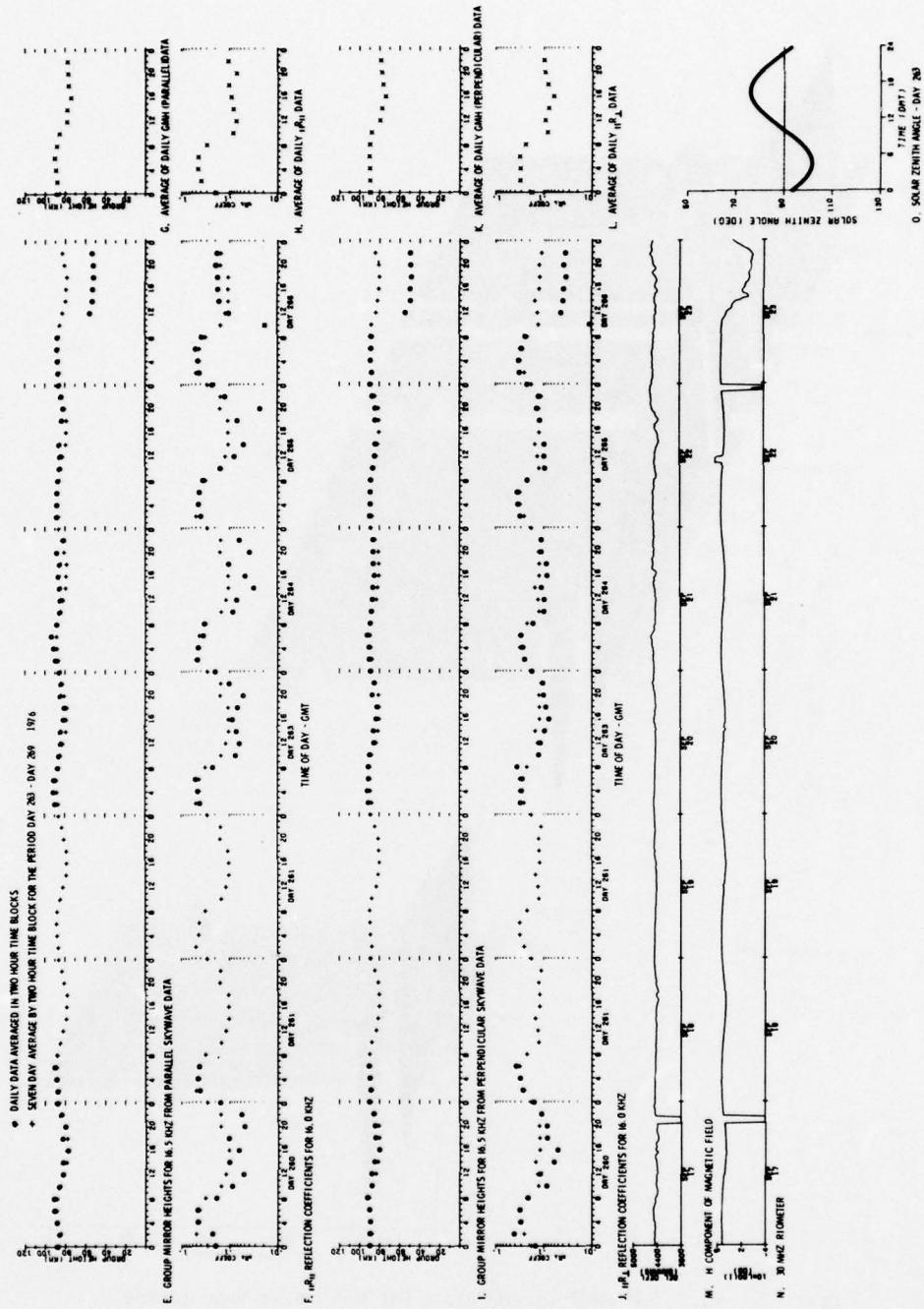


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 260 (17 Sep) - DAY 266 (23 Sep) 1978 (Cont)

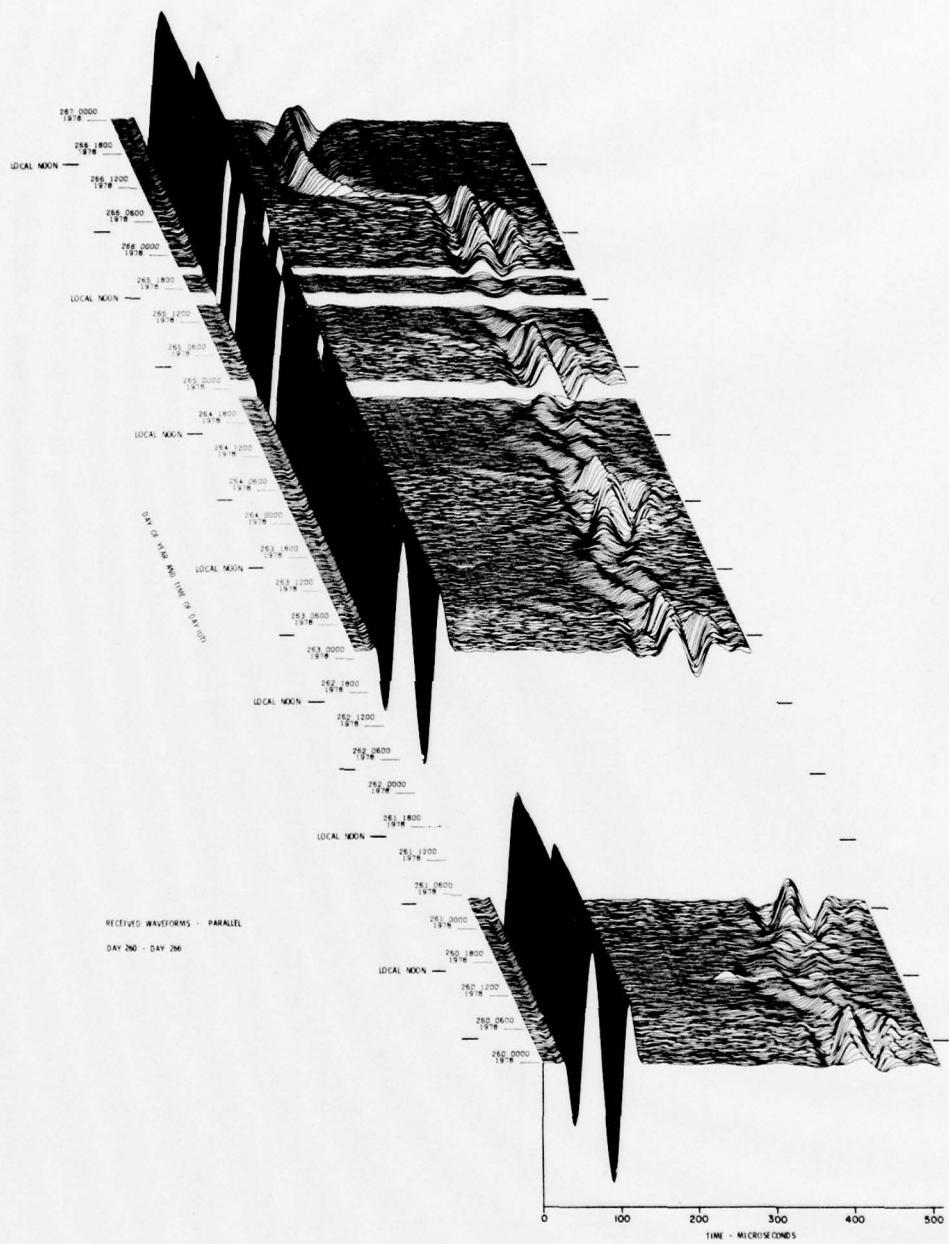


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere,  
DAY 260 (17 Sep) - DAY 266 (23 Sep) 1978 (Cont)  
Part R. II Waveform Display

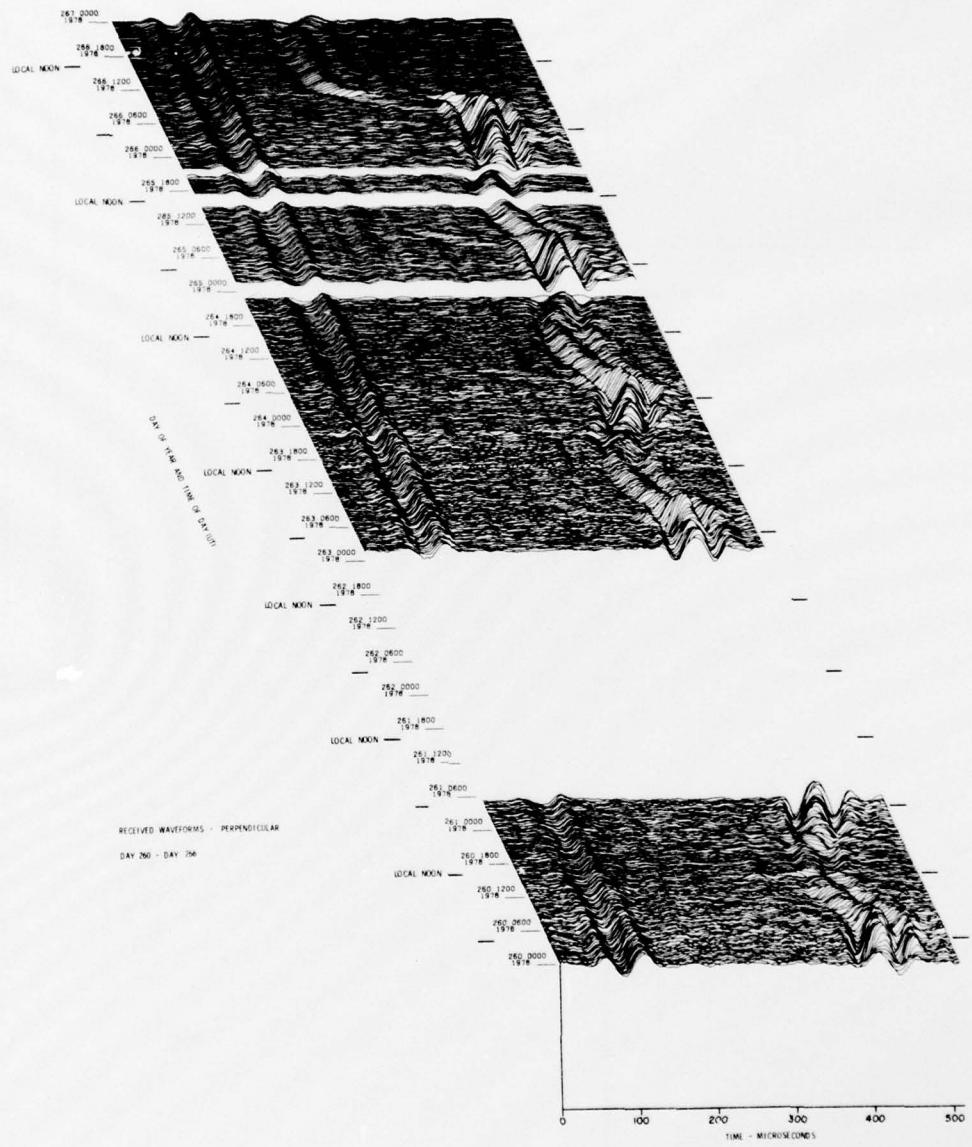


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere,  
DAY 260 (17 Sep) - DAY 266 (23 Sep) 1978 (Cont)  
Part S.  $\perp$  Waveform Display

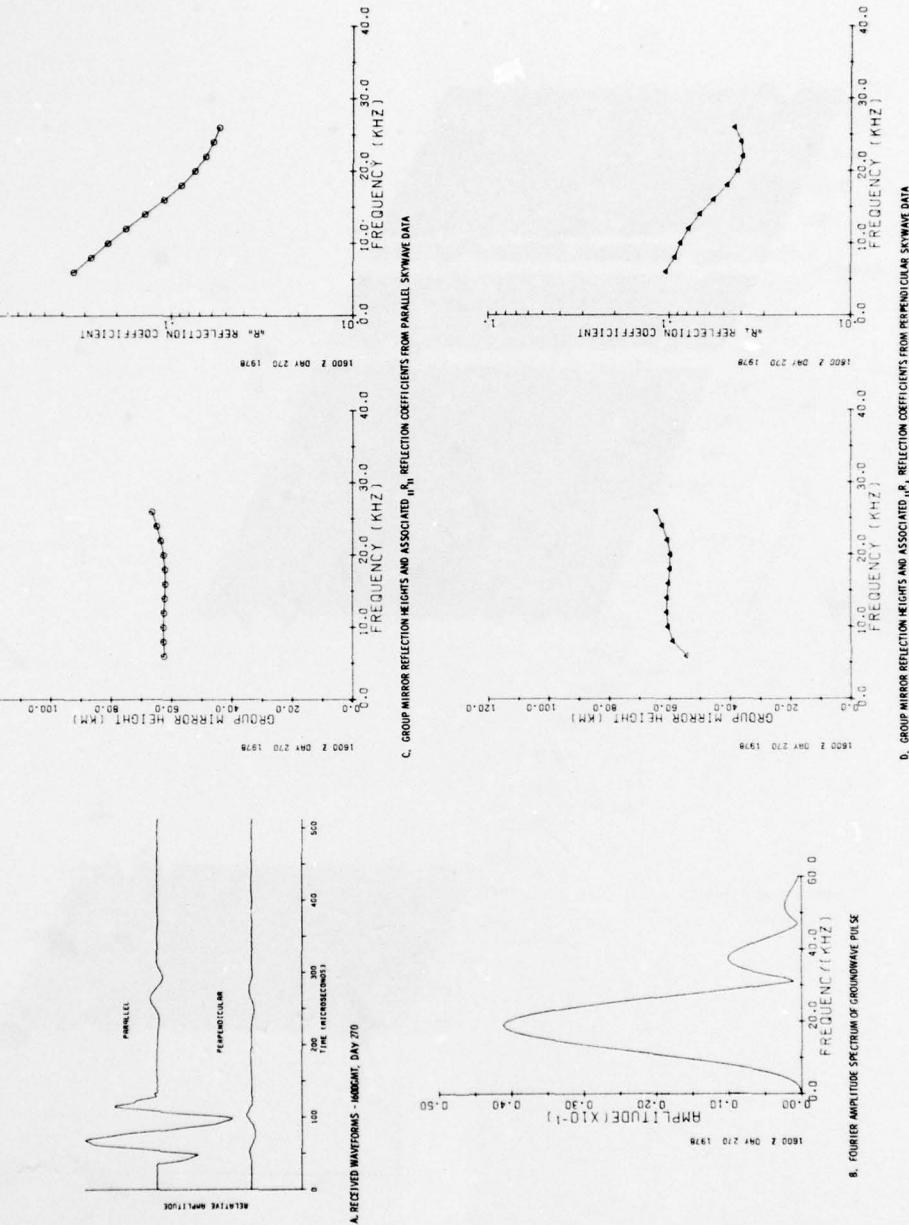


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 267 (24 Sep) - DAY 273 (30 Sep) 1978

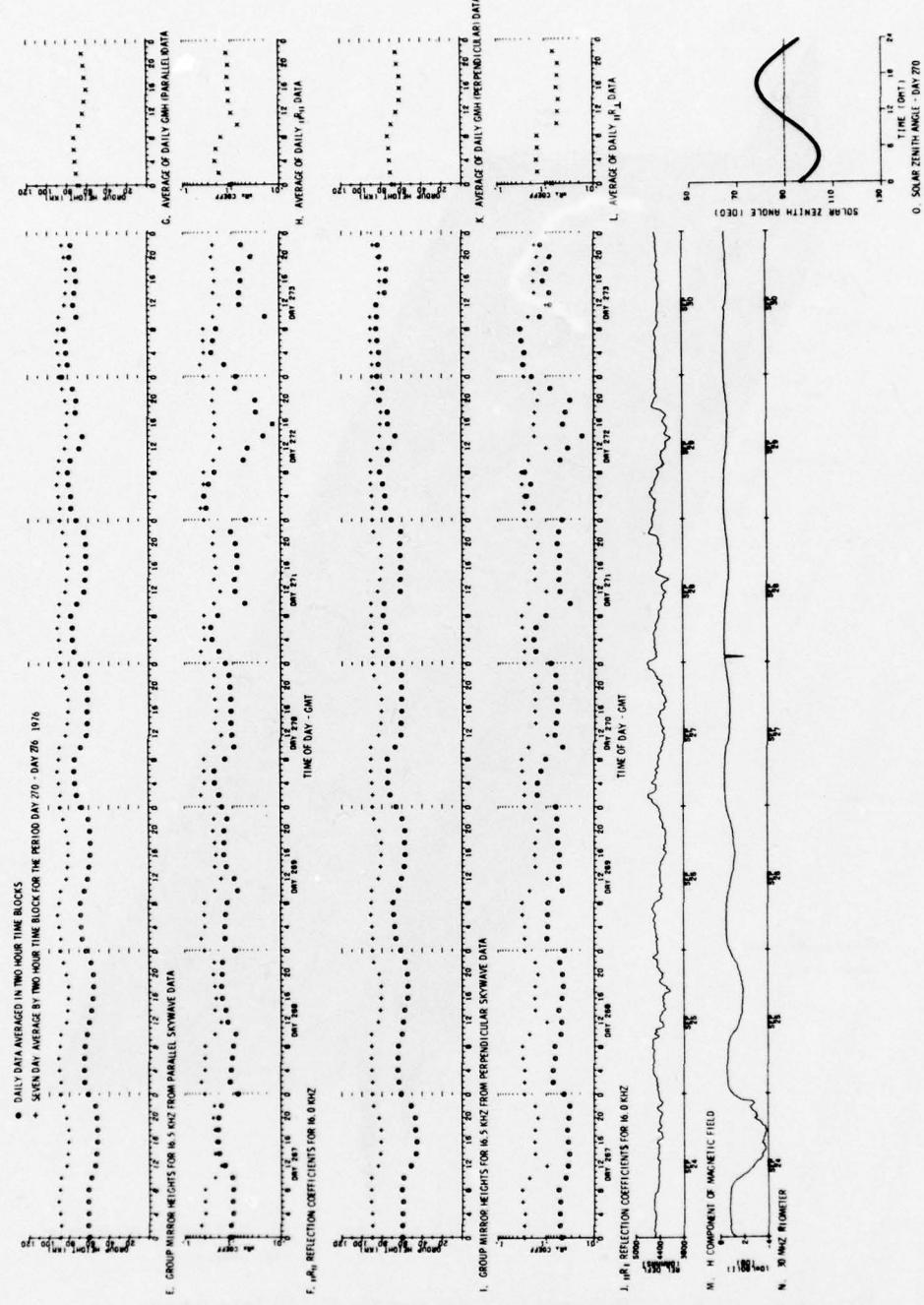


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 267 (24 Sep) - DAY 273 (30 Sep) 1978 (Cont)

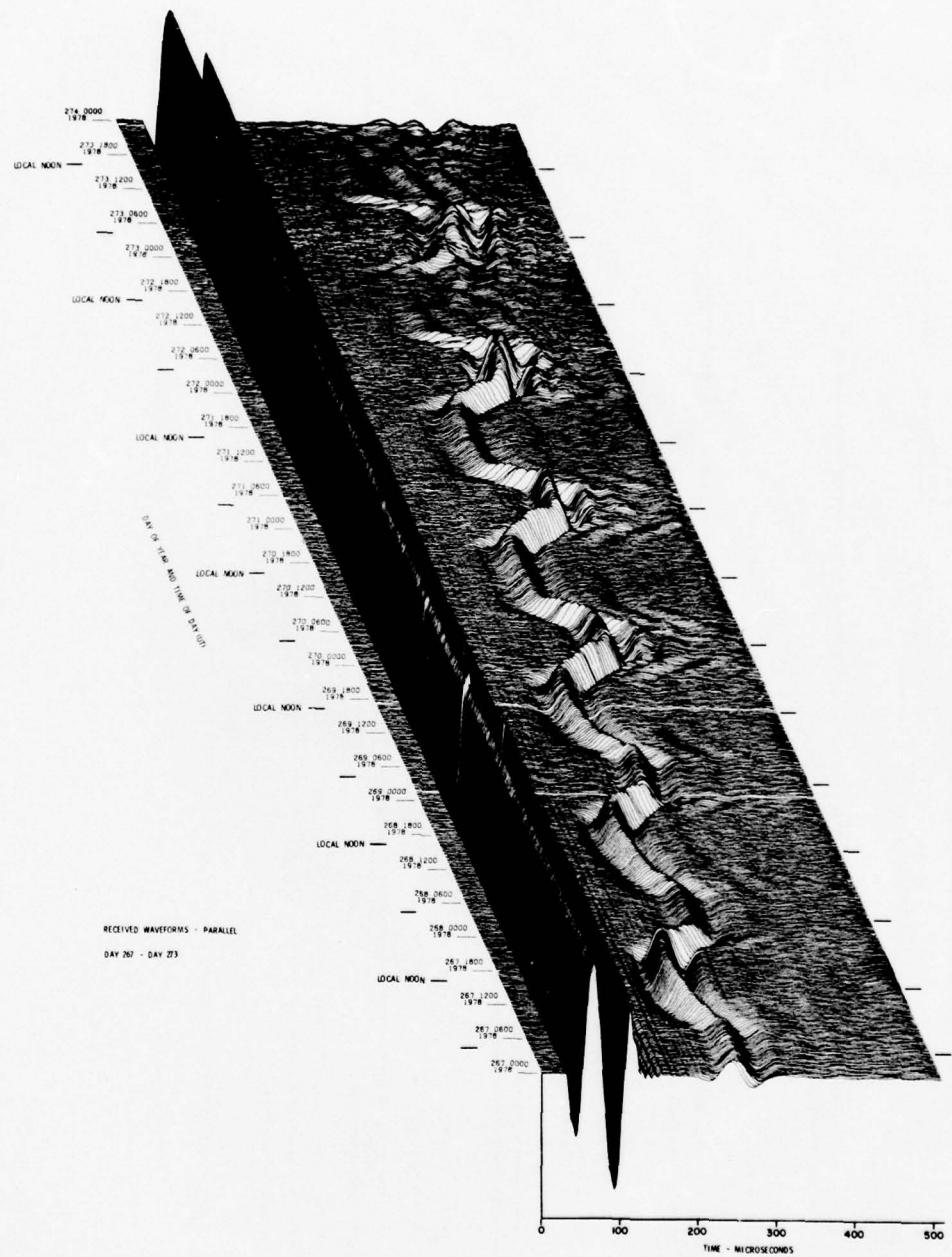


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 267 (24 Sep) — DAY 273 (30 Sep) 1978 (Cont)  
 Part R. II Waveform Display

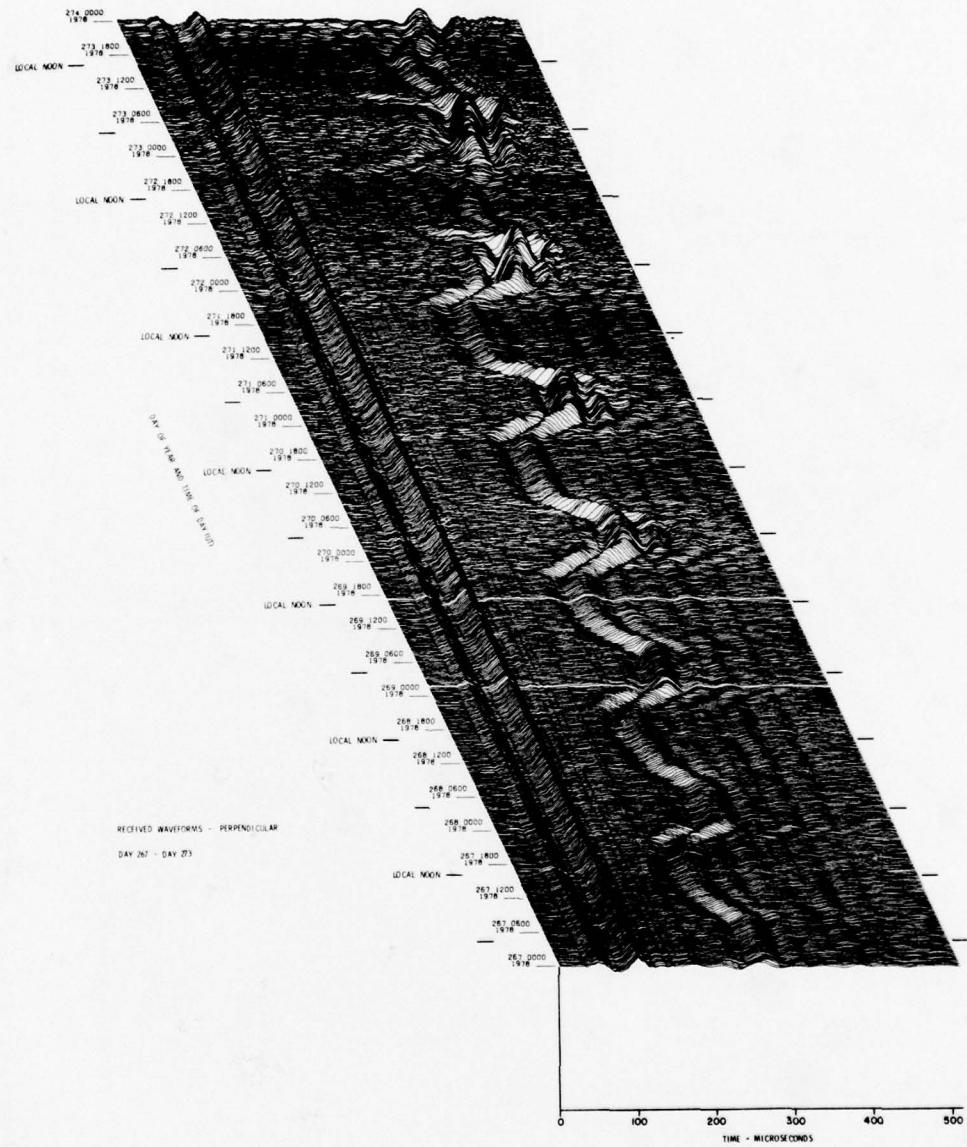


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 267 (24 Sep) — DAY 273 (30 Sep) 1978 (Cont)  
 Part S.  $\perp$  Waveform Display

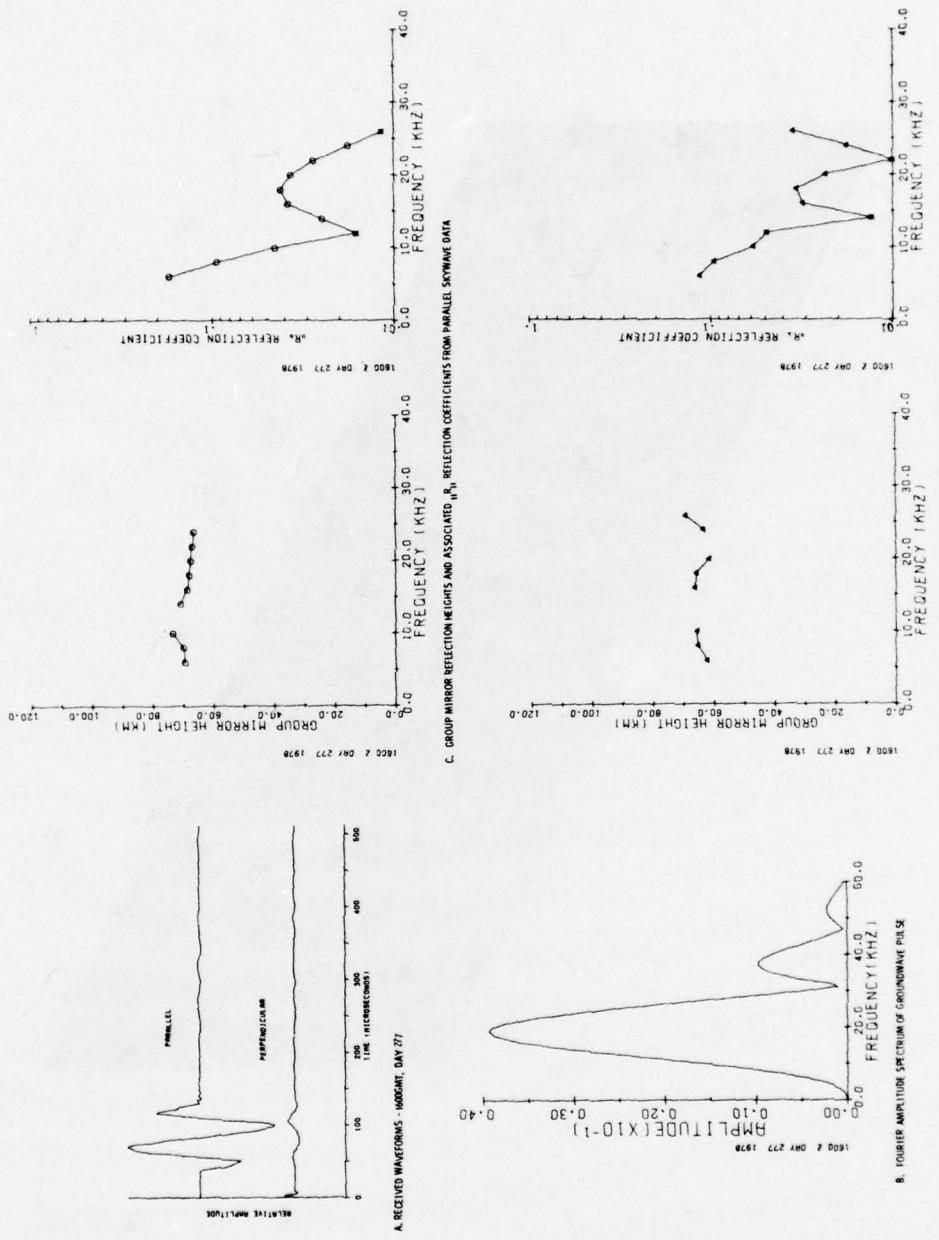


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 274 (1 Oct) — DAY 280 (7 Oct) 1978

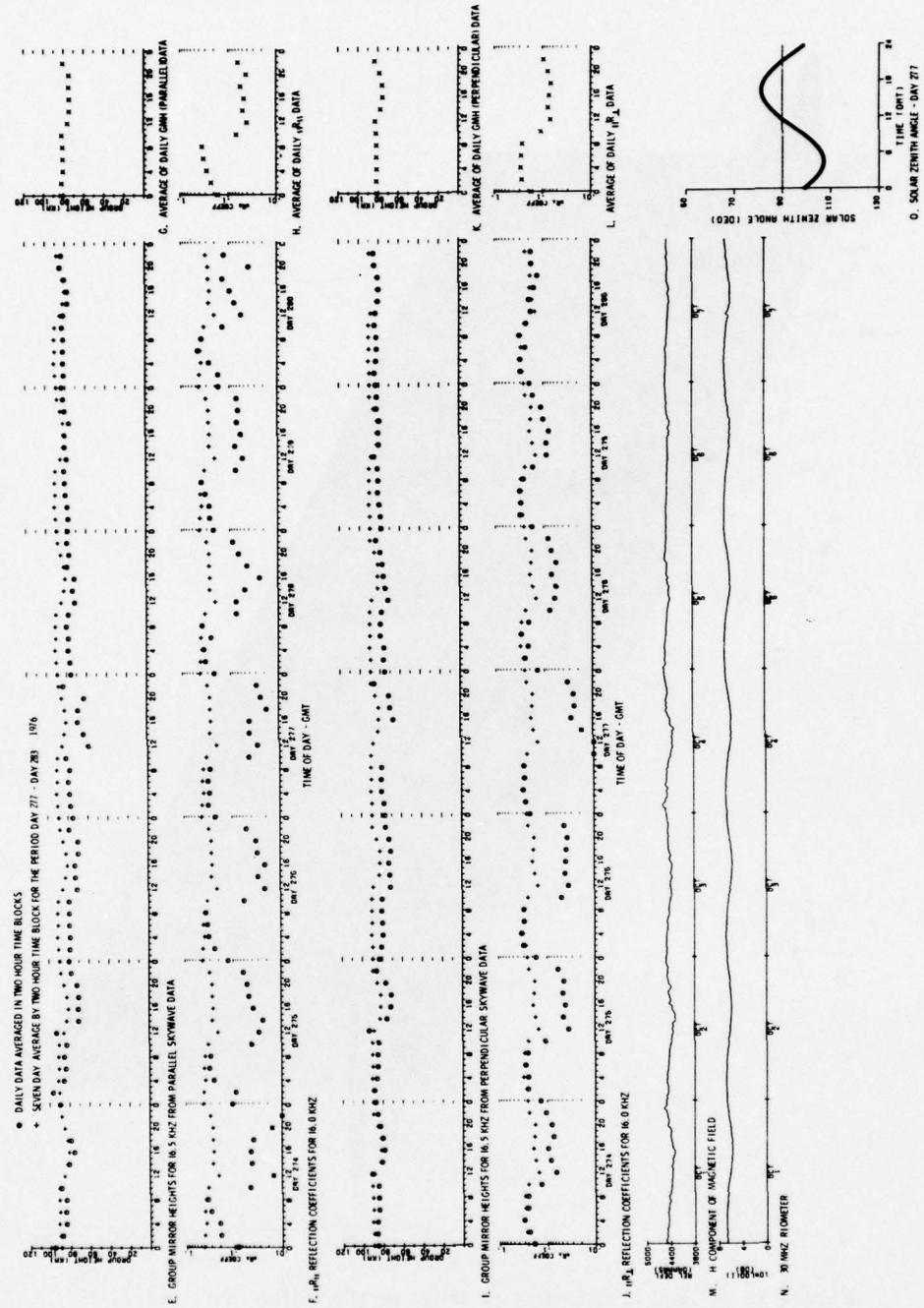


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 274 (1 Oct) – DAY 280 (7 Oct) 1978 (Cont)

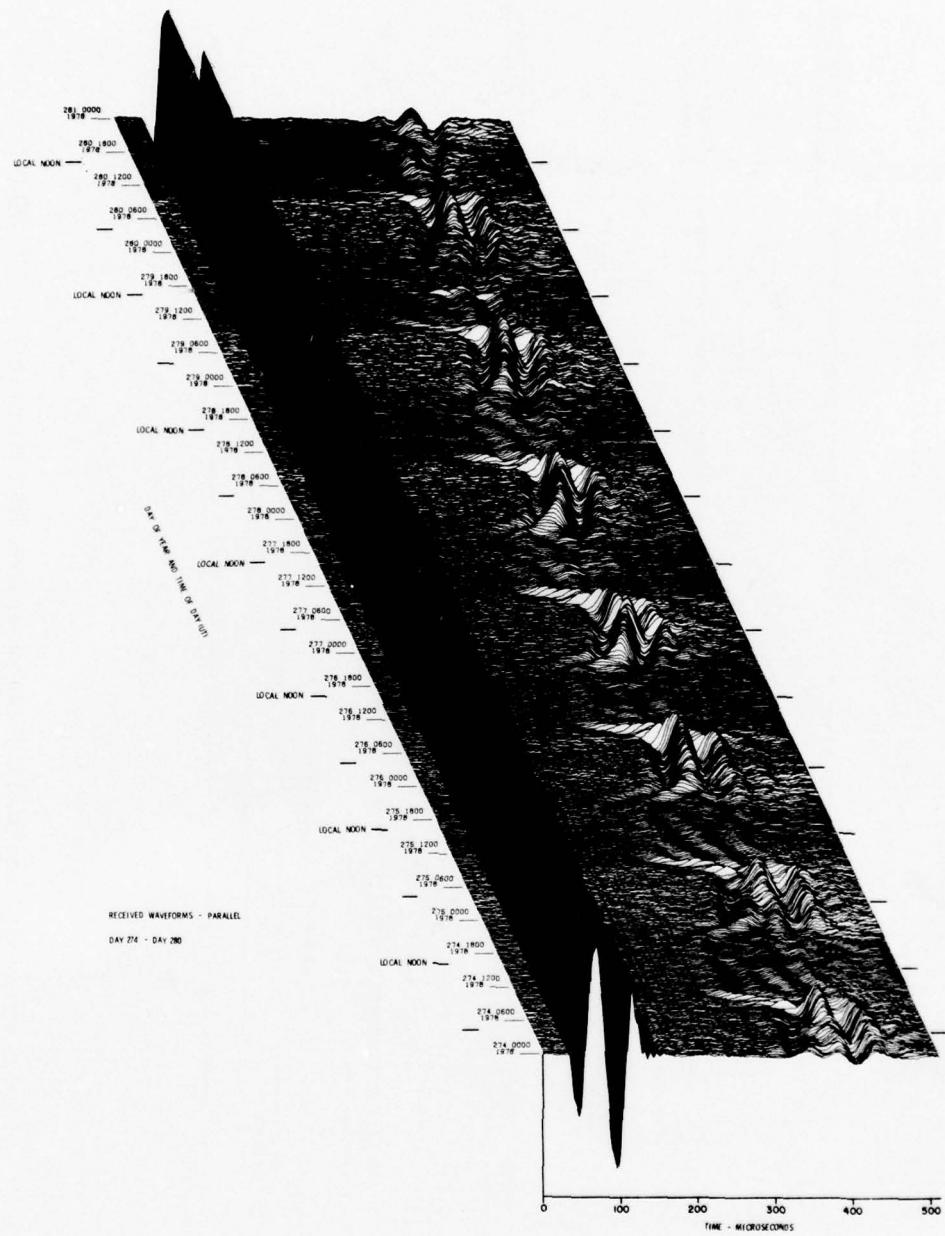


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere,  
DAY 274 (1 Oct) — DAY 280 (7 Oct) 1978 (Cont)  
Part R.  $\parallel$  Waveform Display

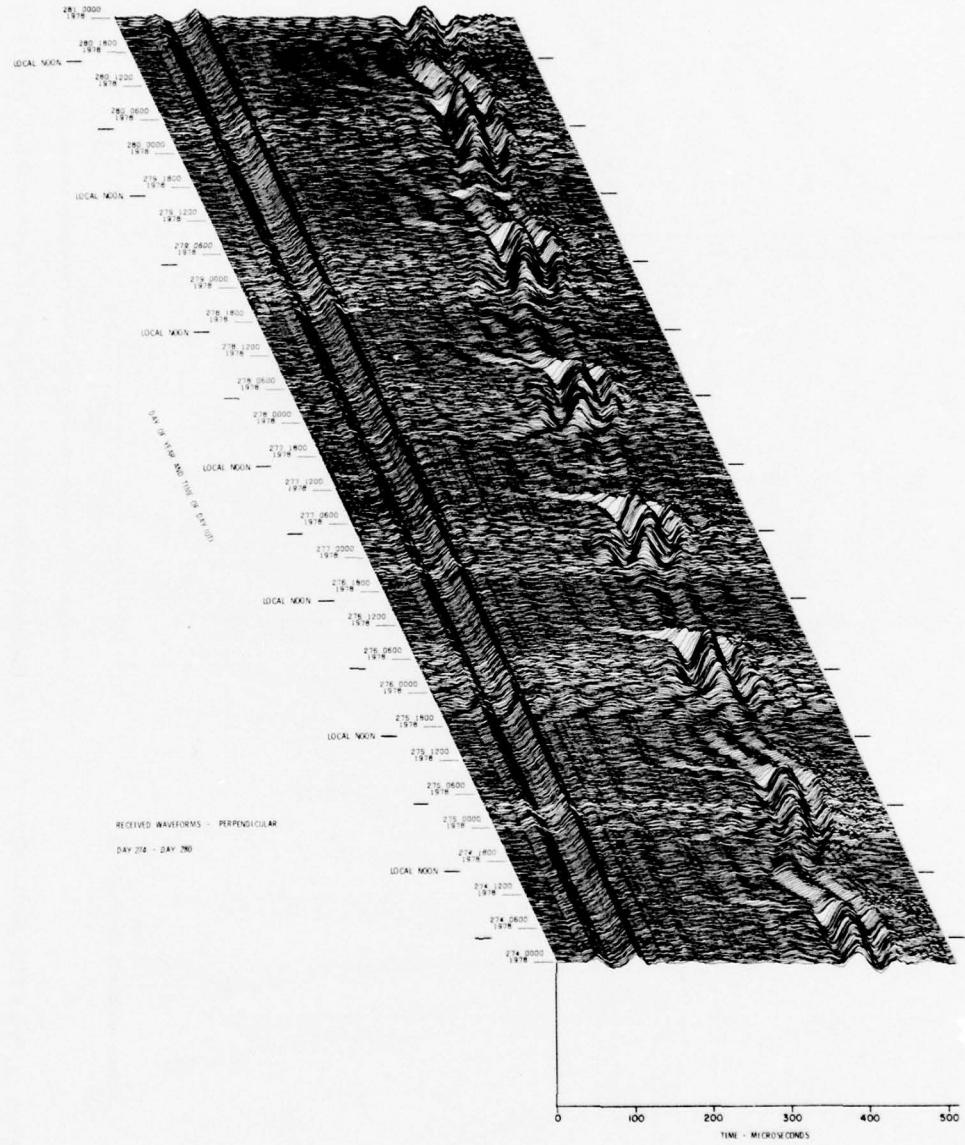


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 274 (1 Oct) - DAY 280 (7 Oct) 1978 (Cont)  
 Part S.  $\perp$  Waveform Display

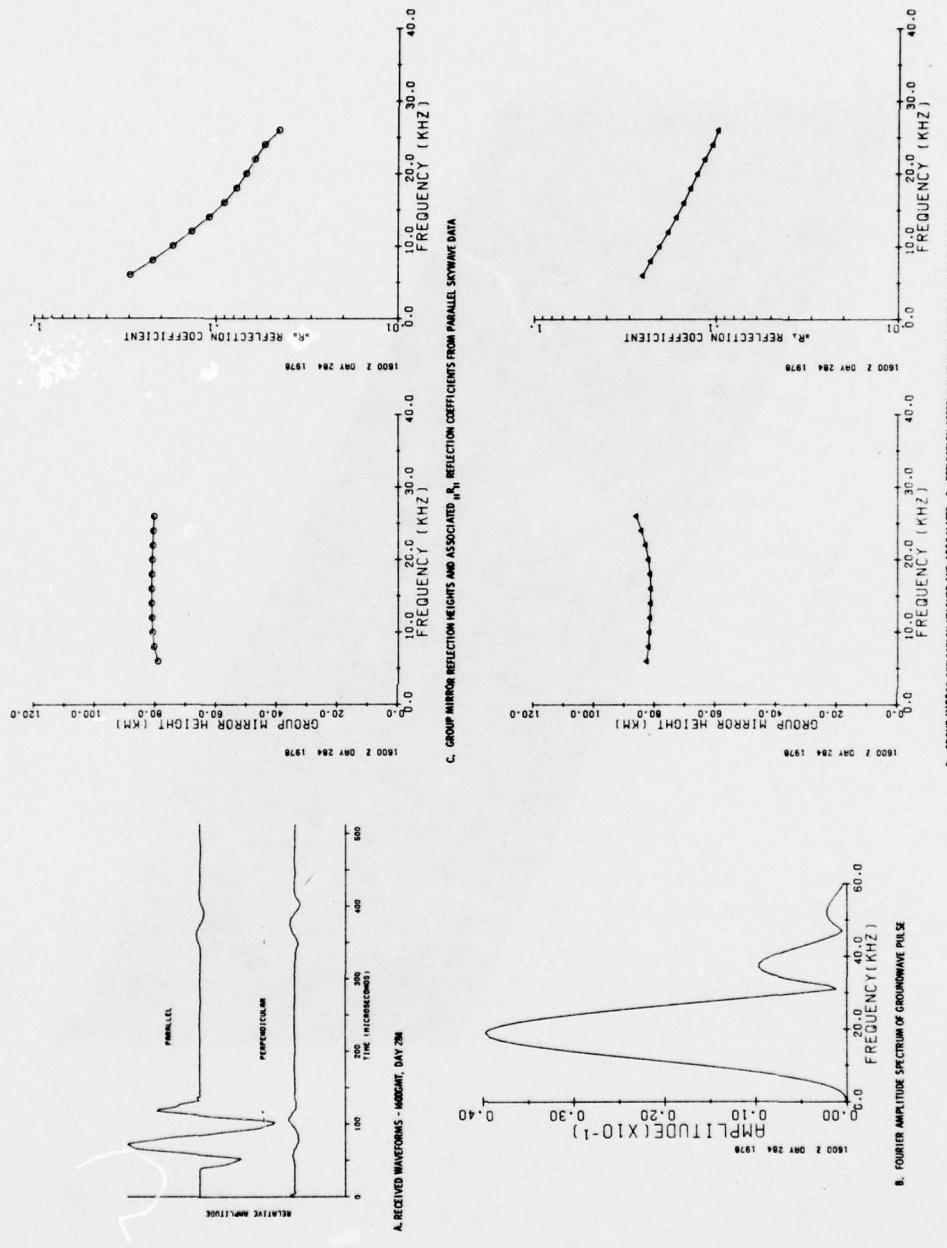


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 281 (8 Oct) - DAY 287 (14 Oct) 1978

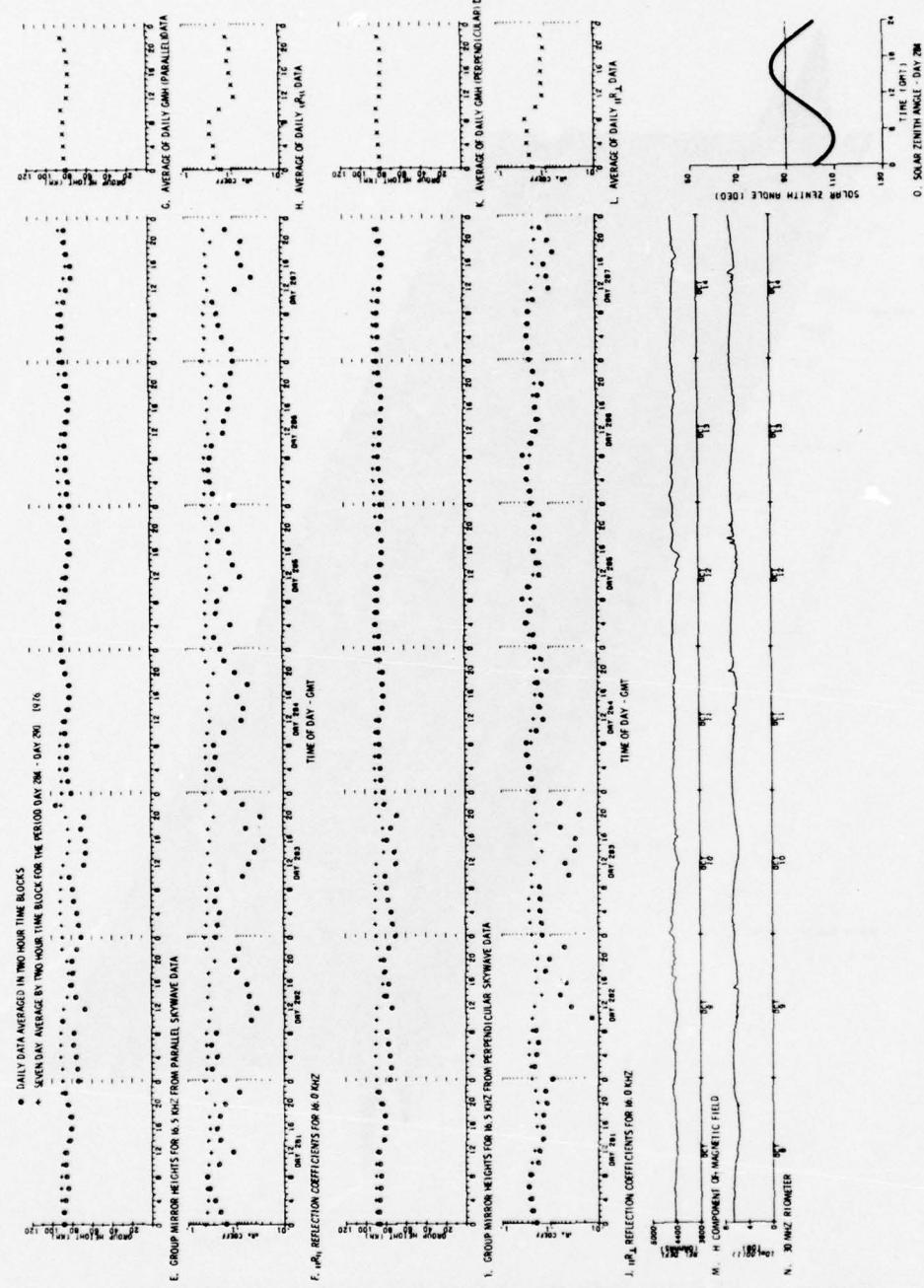


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 281 (8 Oct) - DAY 287 (14 Oct) 1978 (Cont)

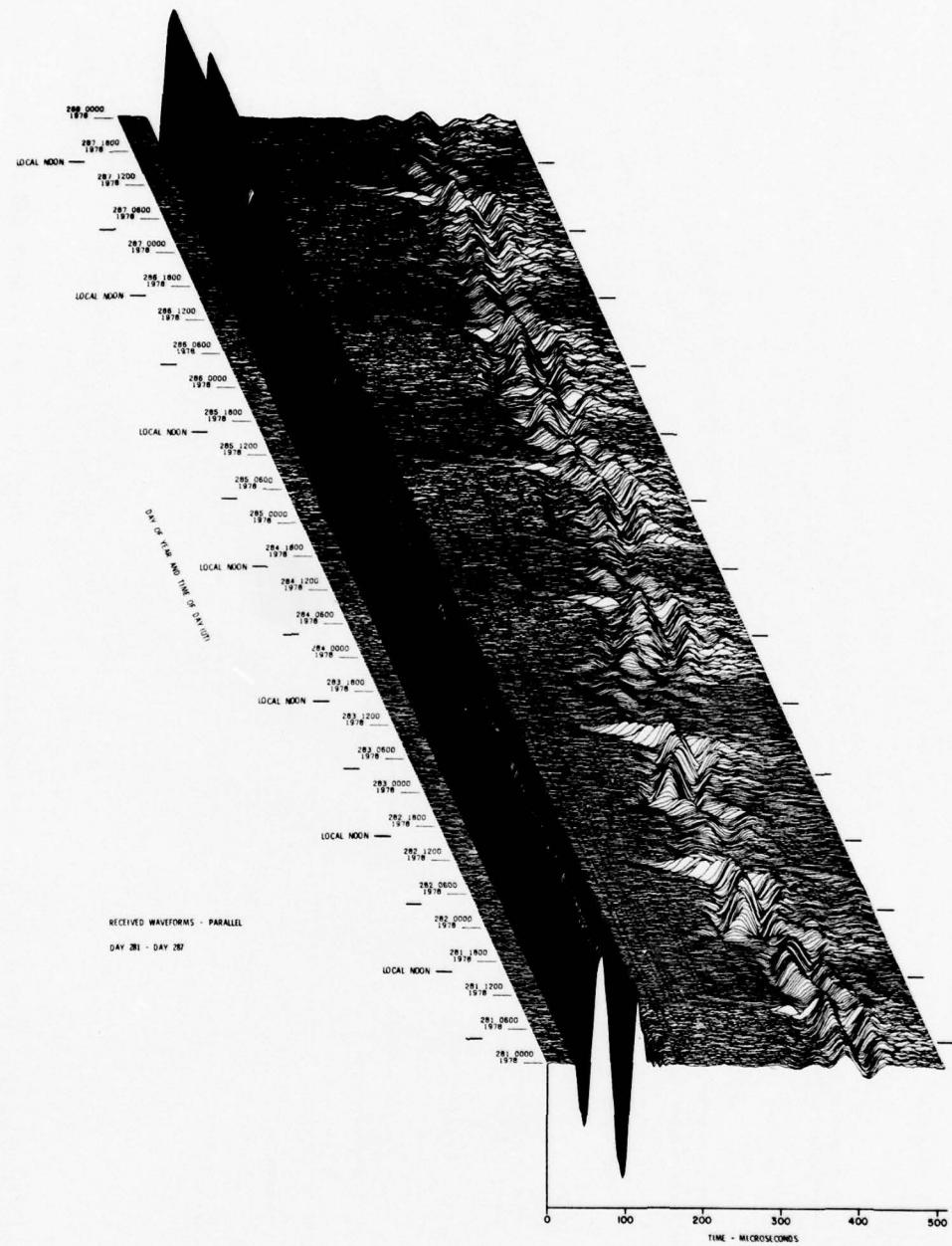


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere,  
DAY 281 (8 Oct) - DAY 287 (14 Oct) 1978 (Cont)  
Part R. II Waveform Display

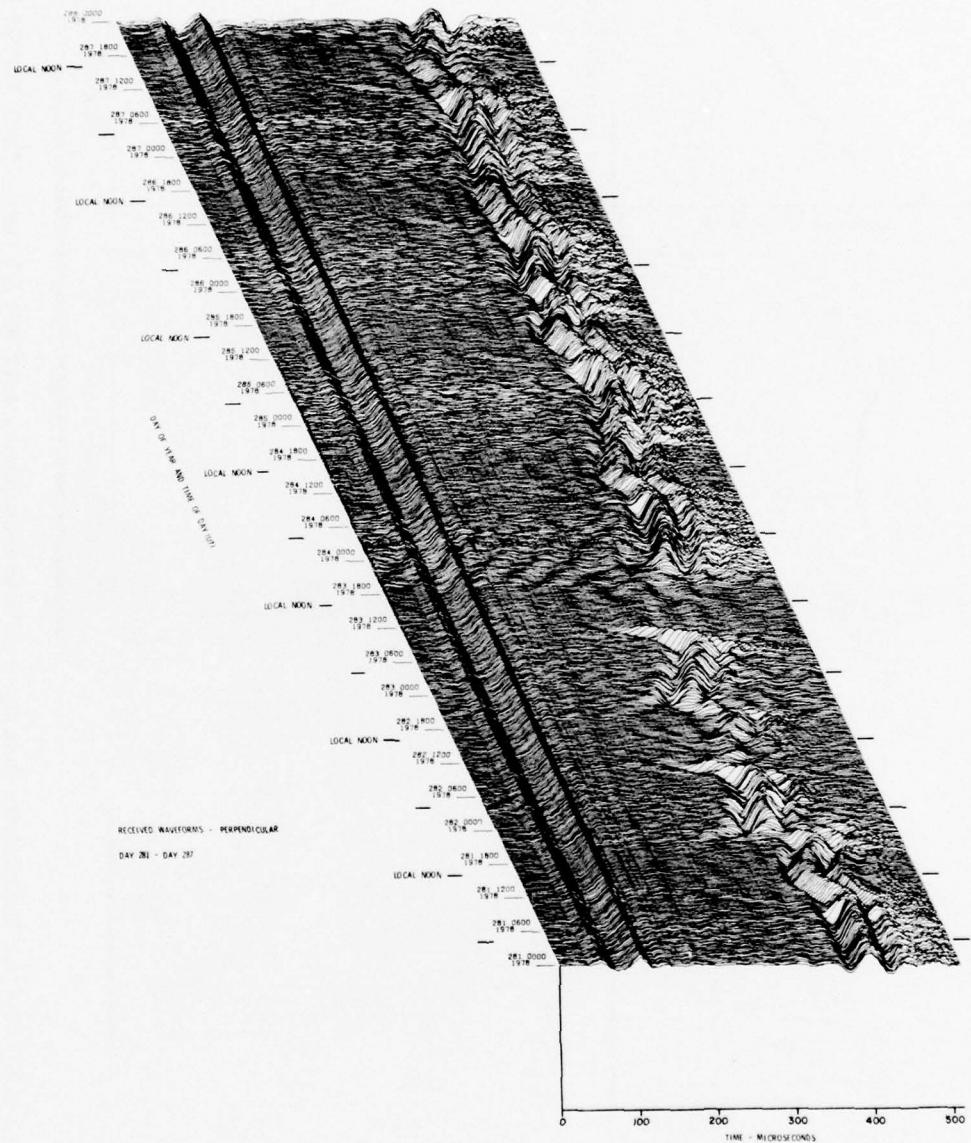


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 281 (8 Oct) - DAY 287 (14 Oct) 1978 (Cont)  
 Part S.  $\perp$  Waveform Display

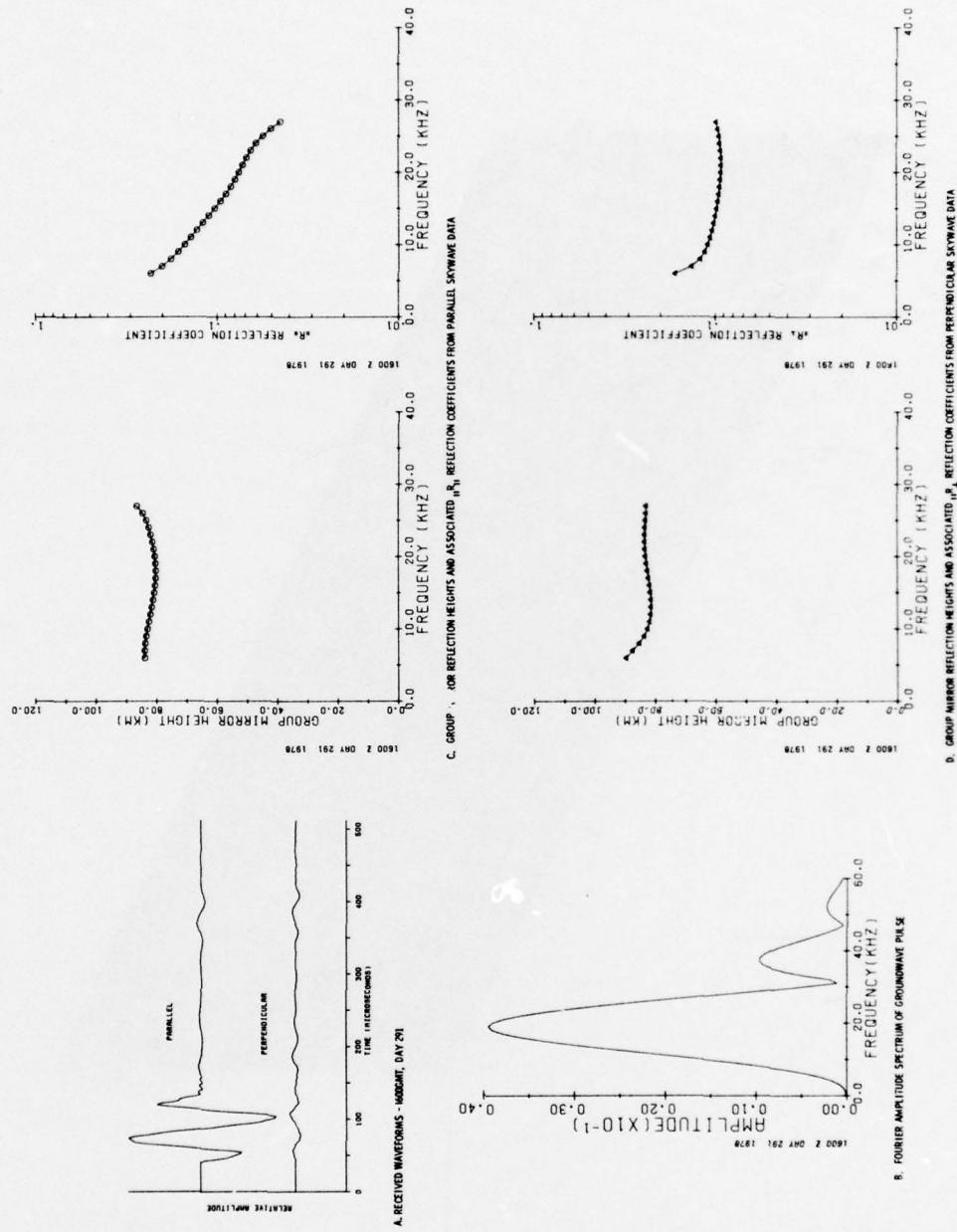


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 288 (15 Oct) — DAY 294 (21 Oct) 1978

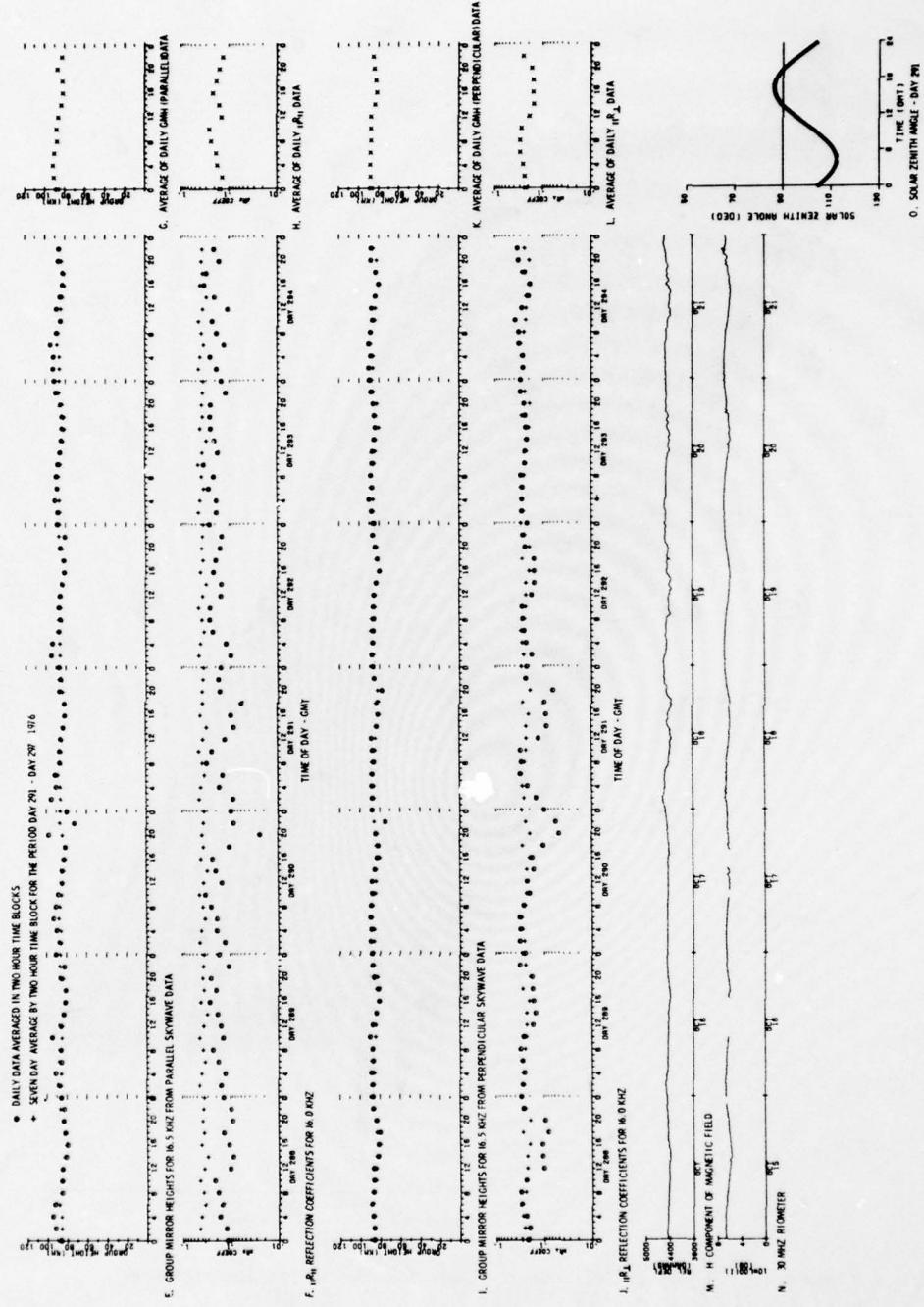


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 288 (15 Oct) - DAY 294 (21 Oct) 1978 (Cont)

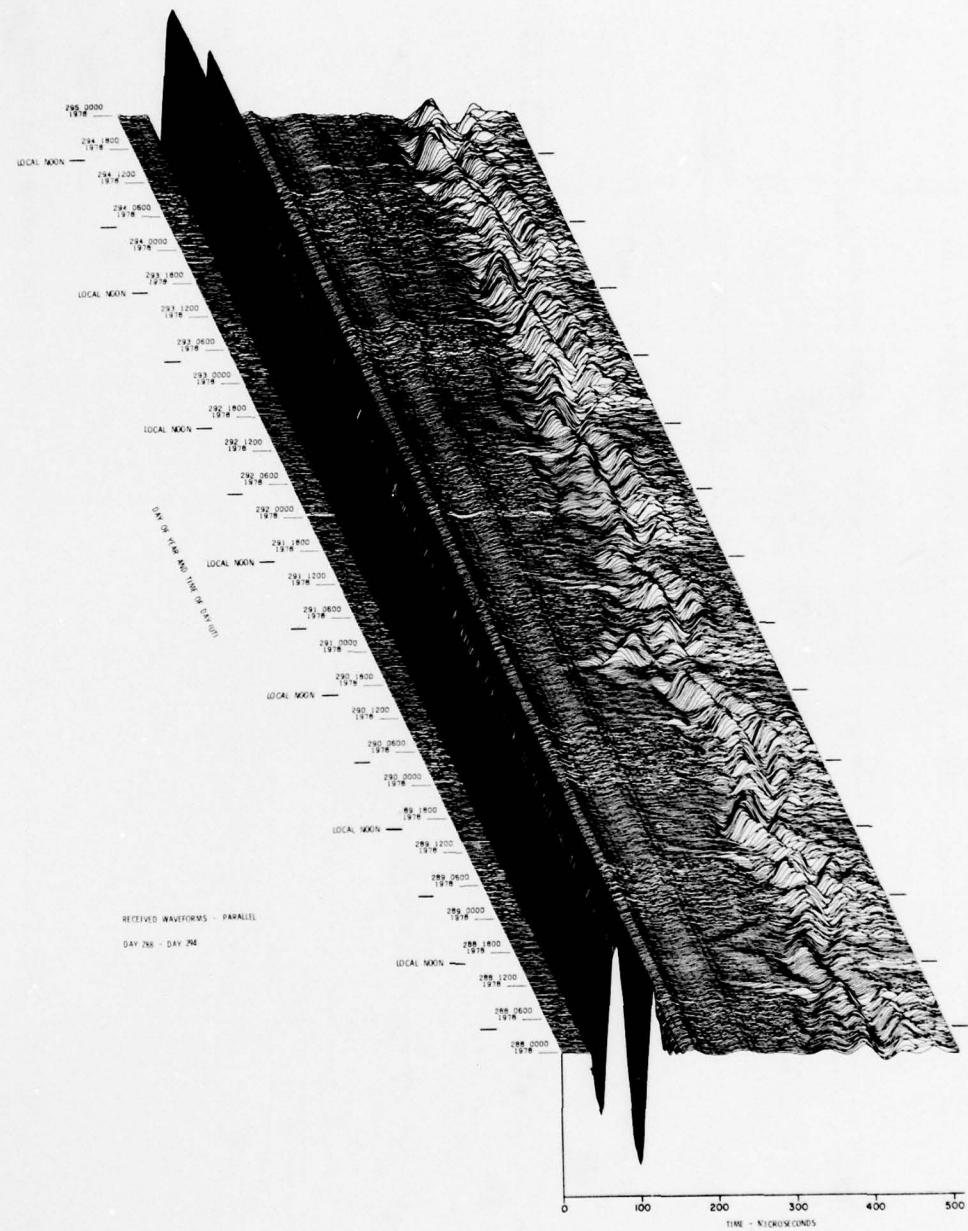


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 288 (15 Oct) - DAY 294 (21 Oct) 1978 (Cont)  
 Part R. II Waveform Display

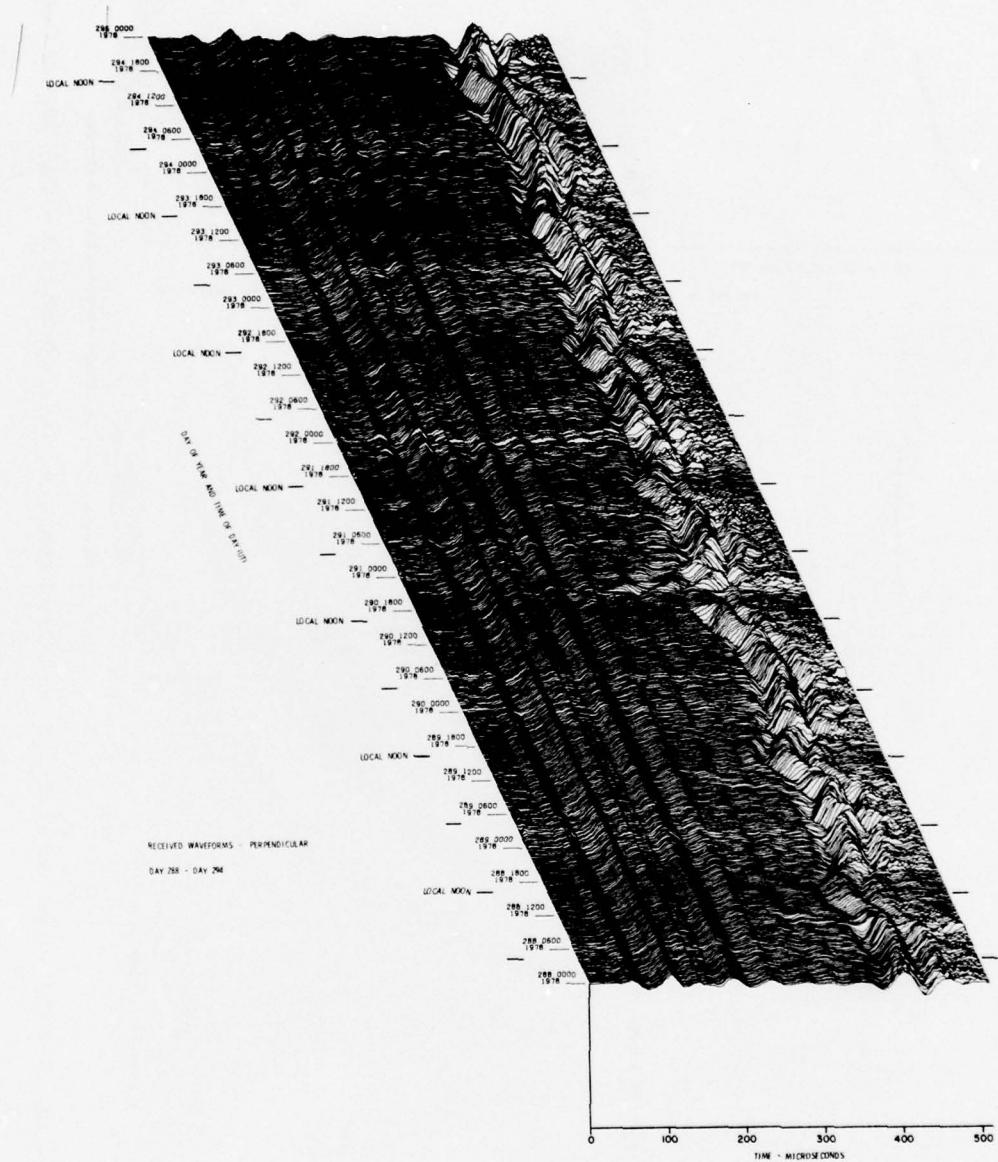


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere,  
DAY 288 (15 Oct) - DAY 294 (21 Oct) 1978 (Cont)  
Part S.  $\perp$  Waveform Display

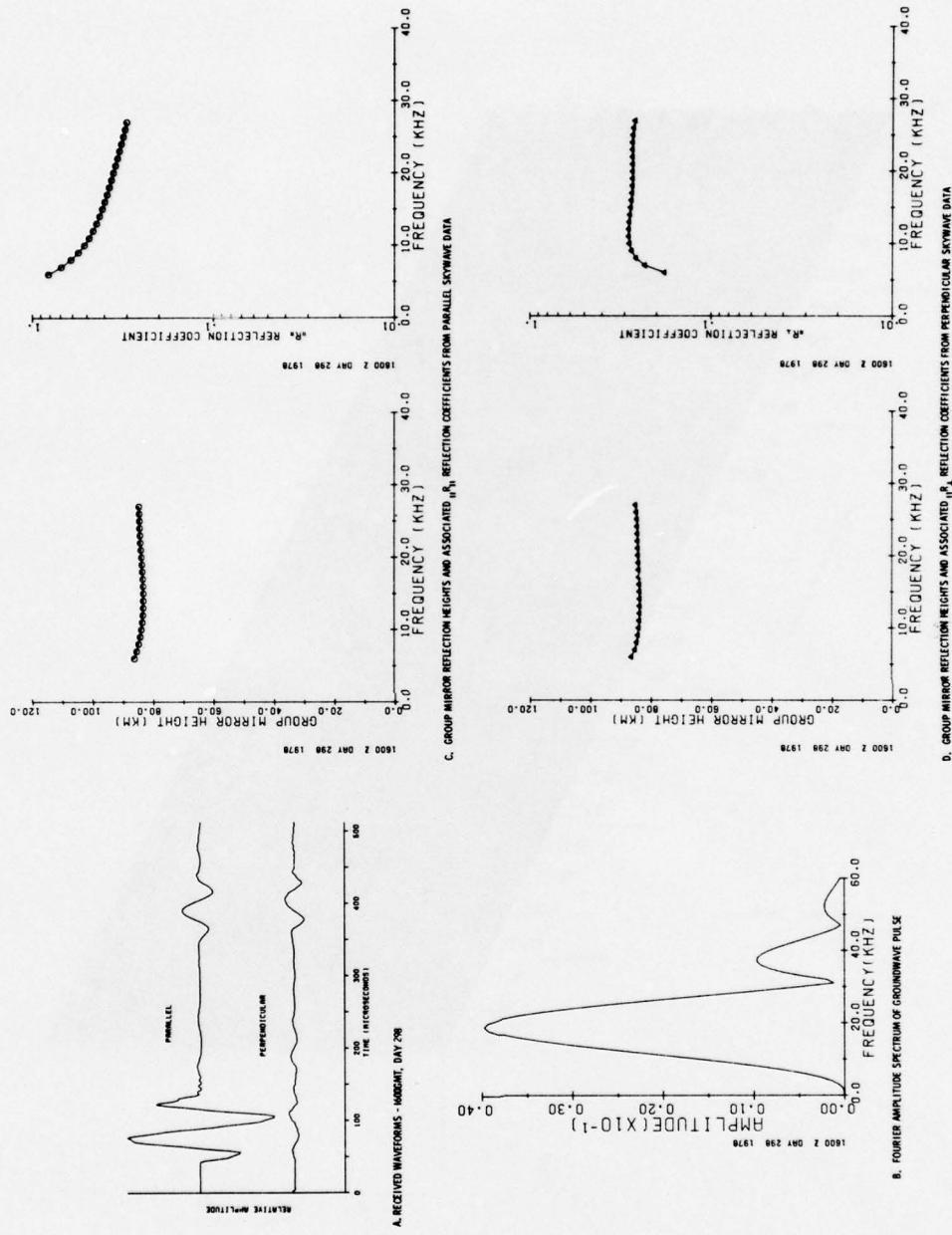


Figure 10. VL/F/LF Reflectivity Data for the Polar Ionosphere, DAY 295 (22 Oct) — DAY 301 (28 Oct) 1978

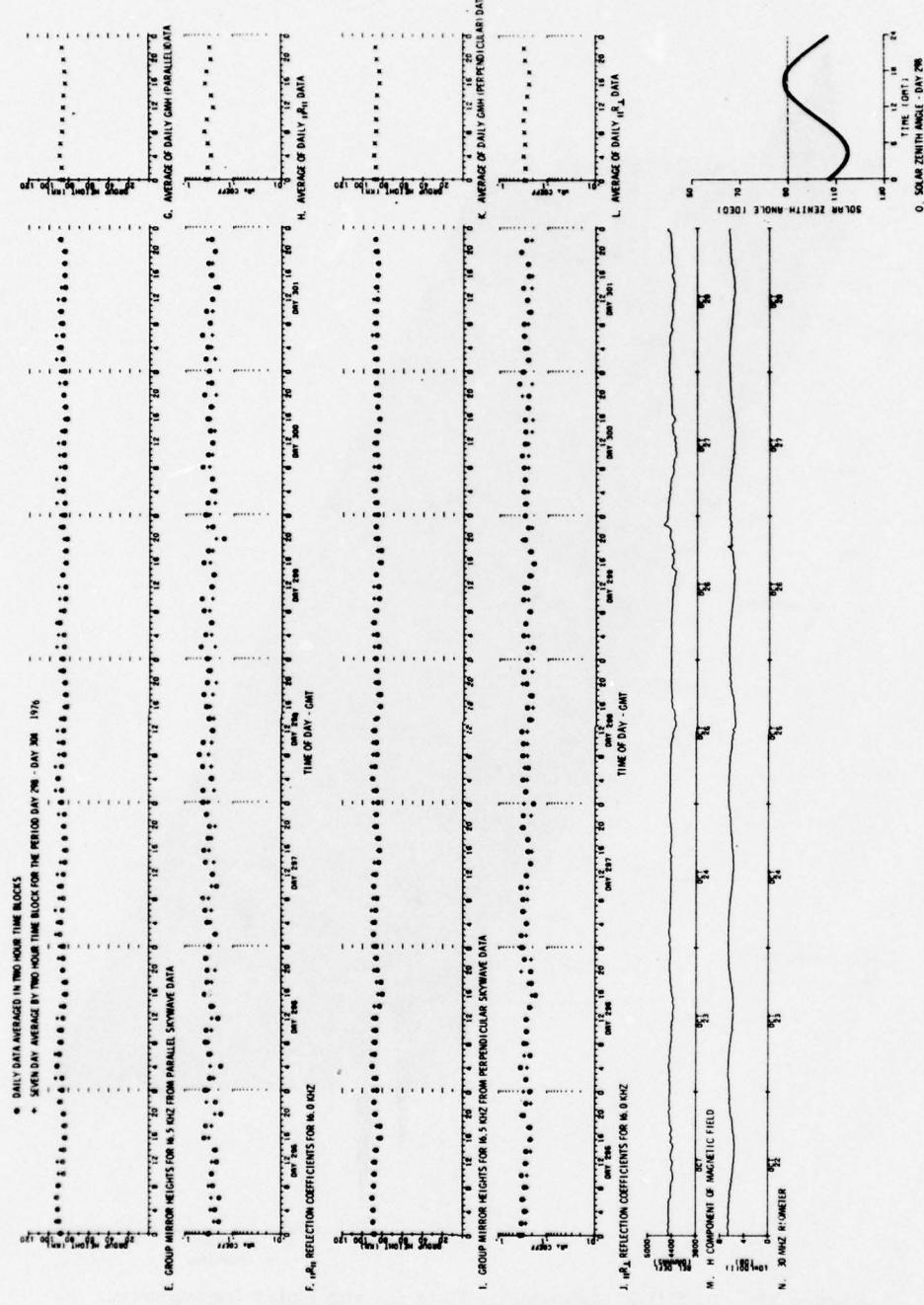


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 295 (22 Oct) - DAY 301 (28 Oct) 1978 (Cont)

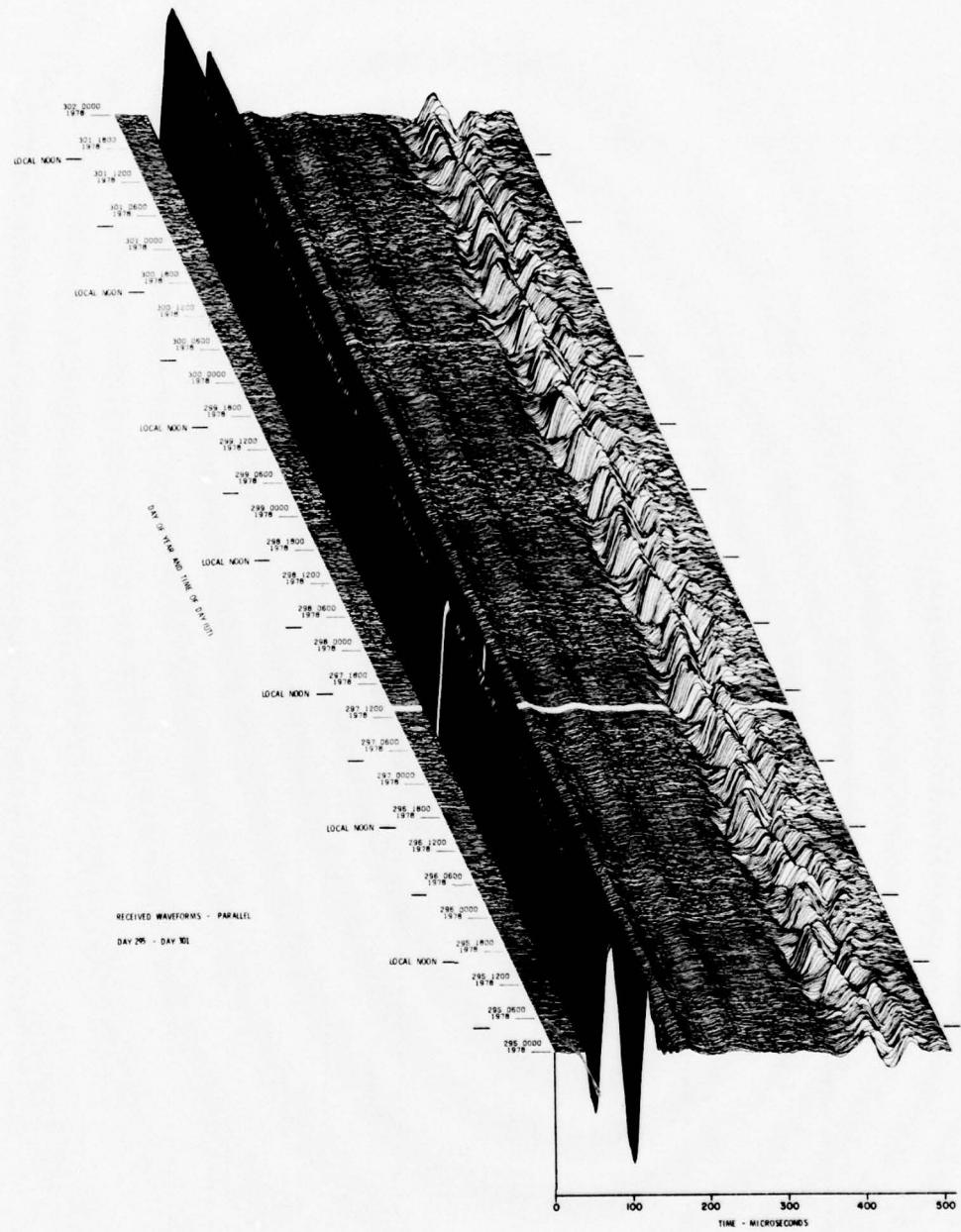


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere,  
DAY 295 (22 Oct) — DAY 301 (28 Oct) 1978 (Cont)  
Part R. II Waveform Display

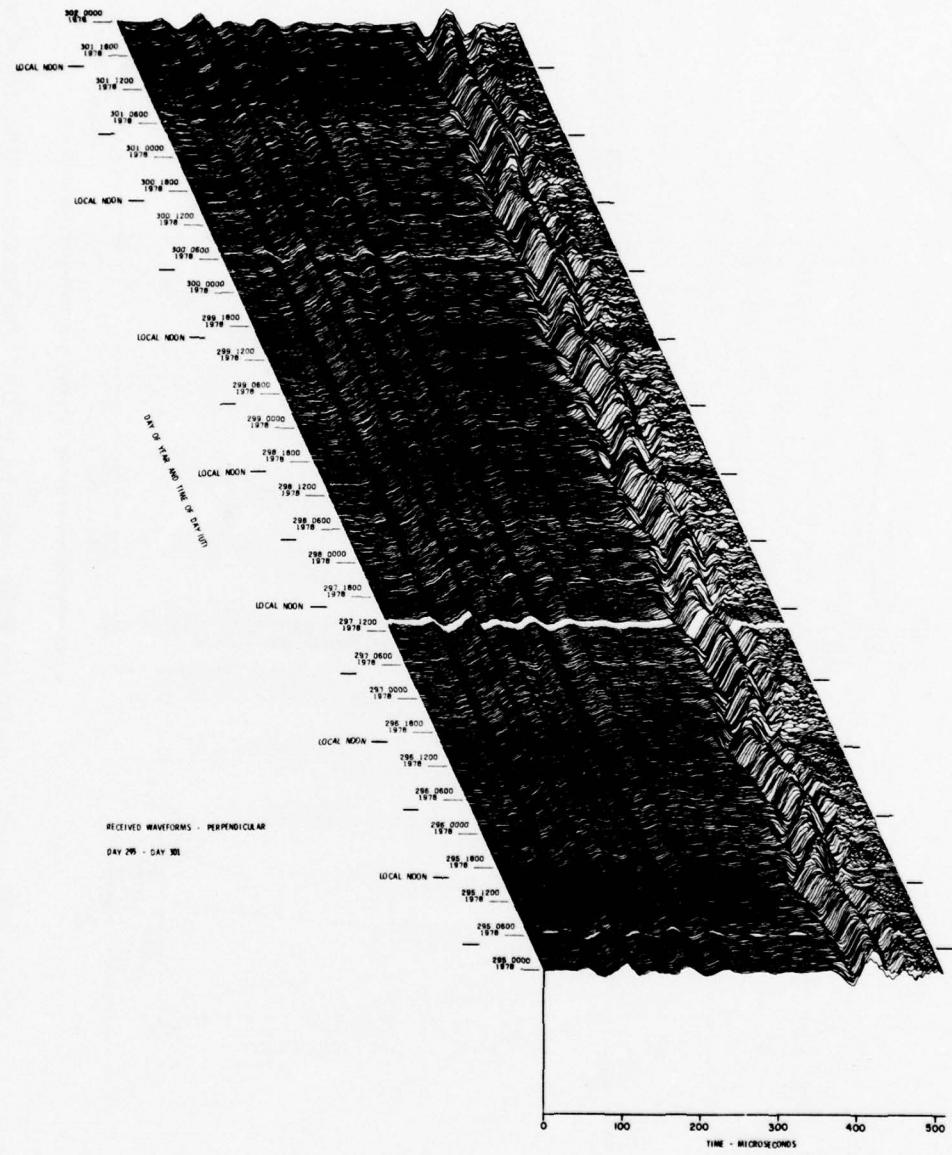


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 295 (22 Oct) - DAY 301 (28 Oct) 1978 (Cont)  
 Part S.  $\perp$  Waveform Display

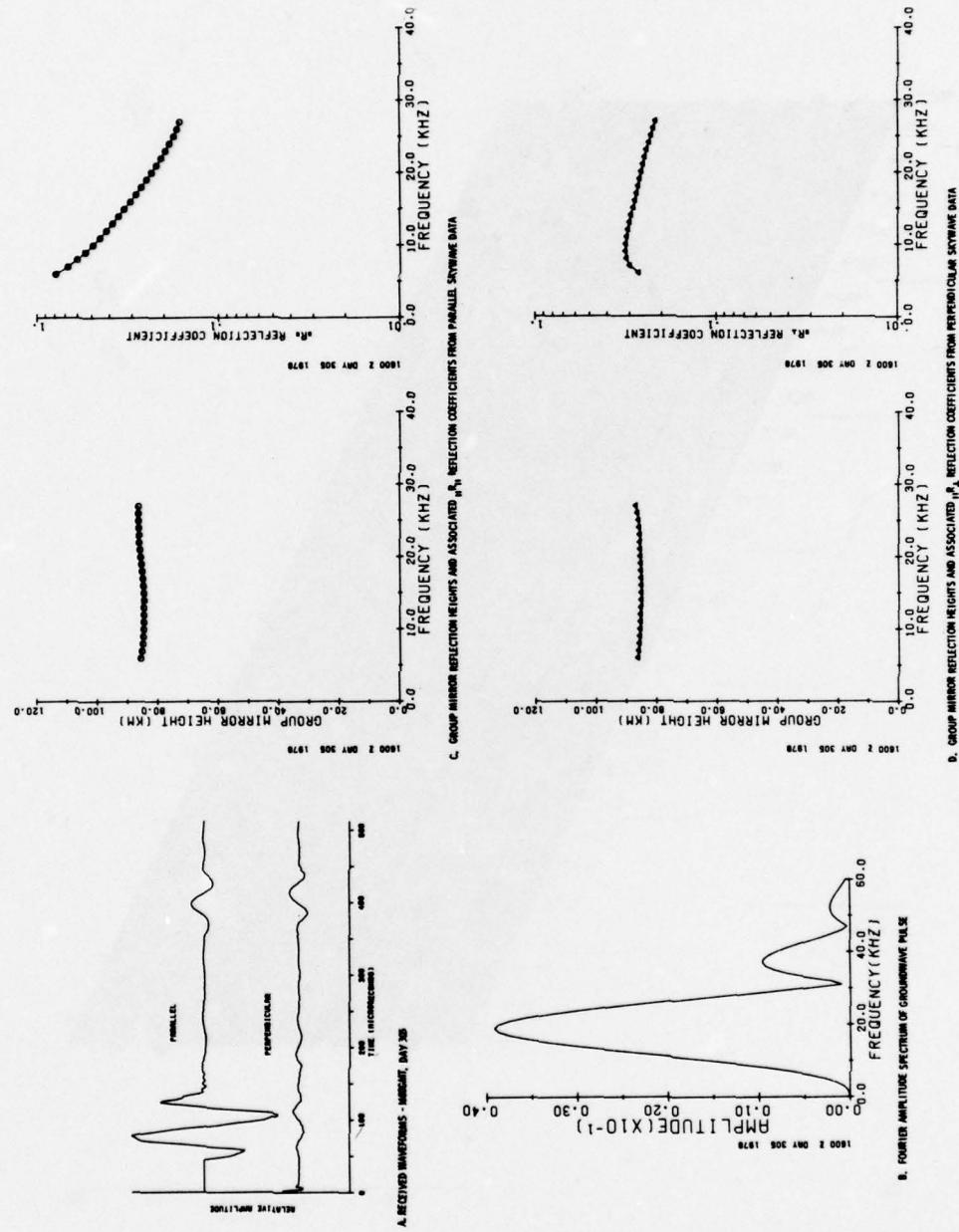


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 302 (29 Oct) - DAY 308 (4 Nov) 1978

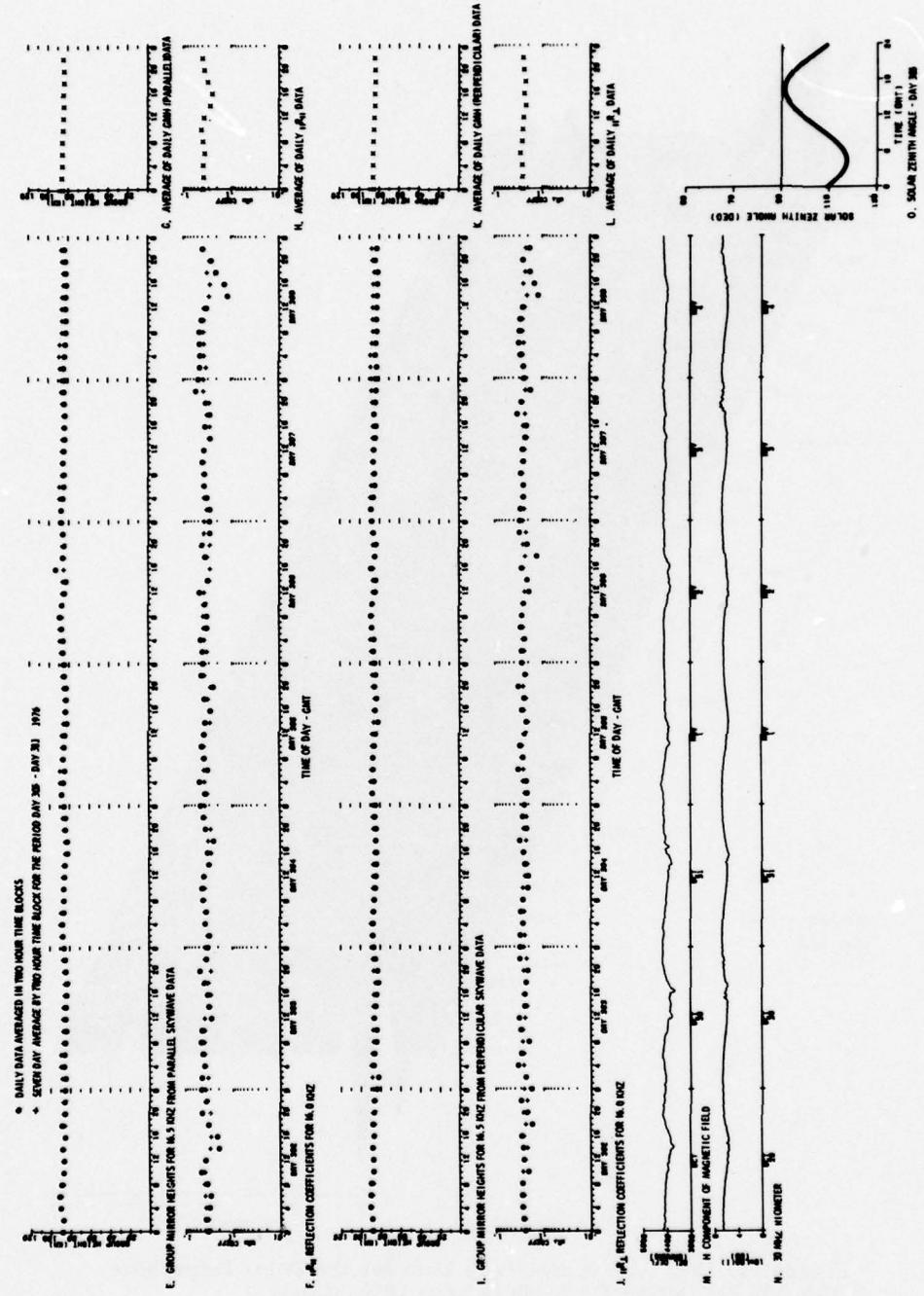


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 302 (29 Oct) - DAY 308 (4 Nov) 1978 (Cont)

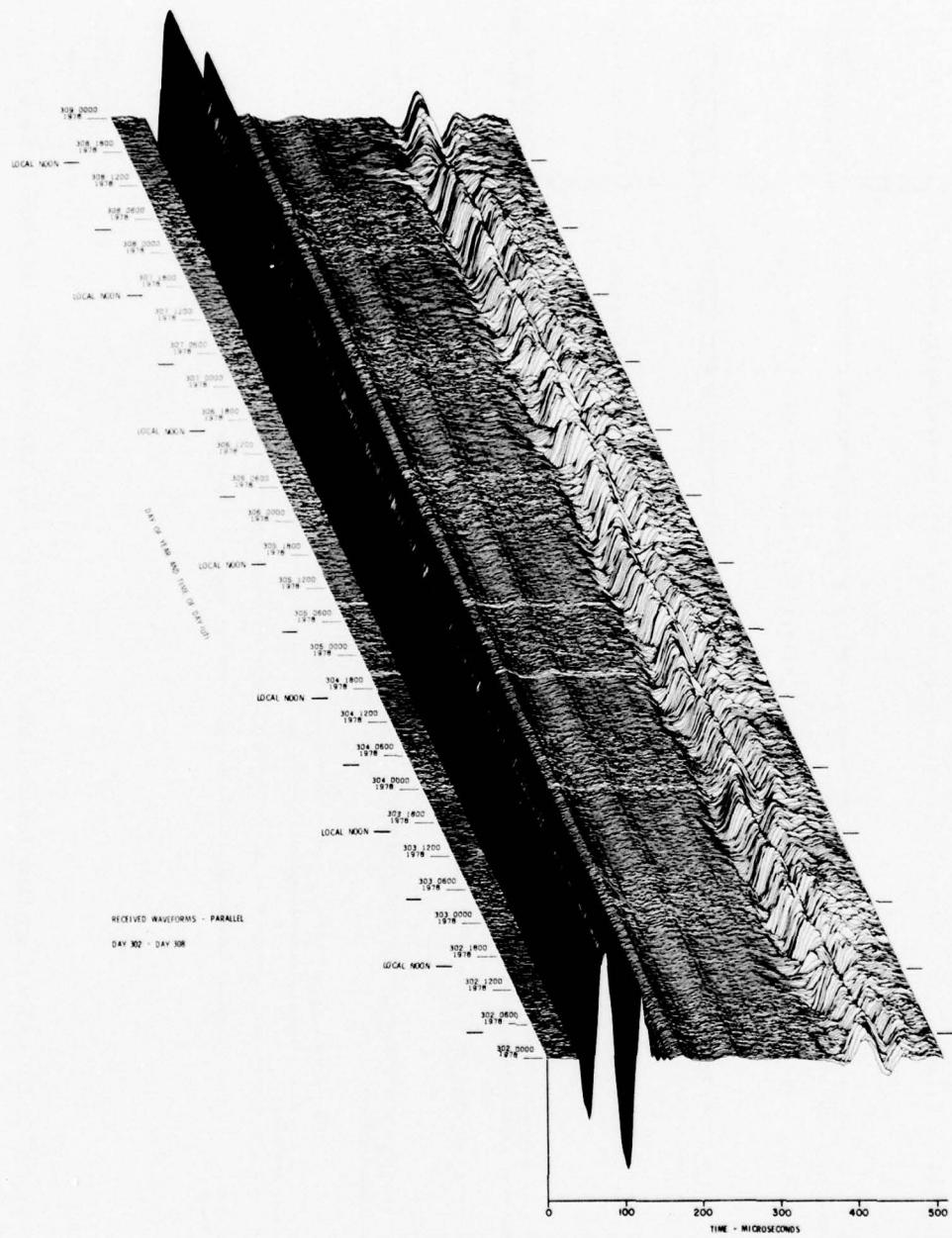


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 302 (29 Oct) - DAY 308 (4 Nov) 1978 (Cont)  
 Part R. || Waveform Display

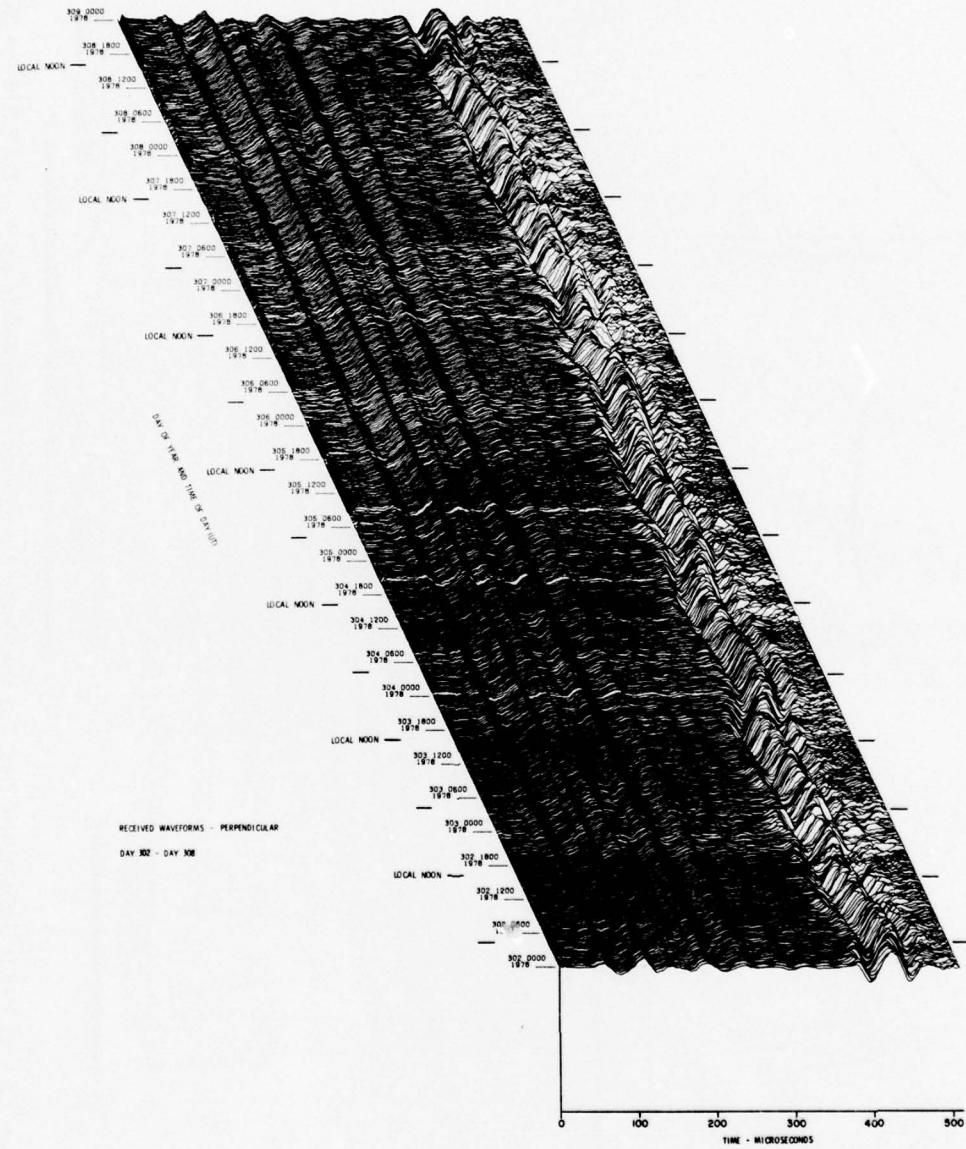


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere,  
DAY 302 (29 Oct) - DAY 308 (4 Nov) 1978 (Cont)  
Part S.  $\perp$  Waveform Display

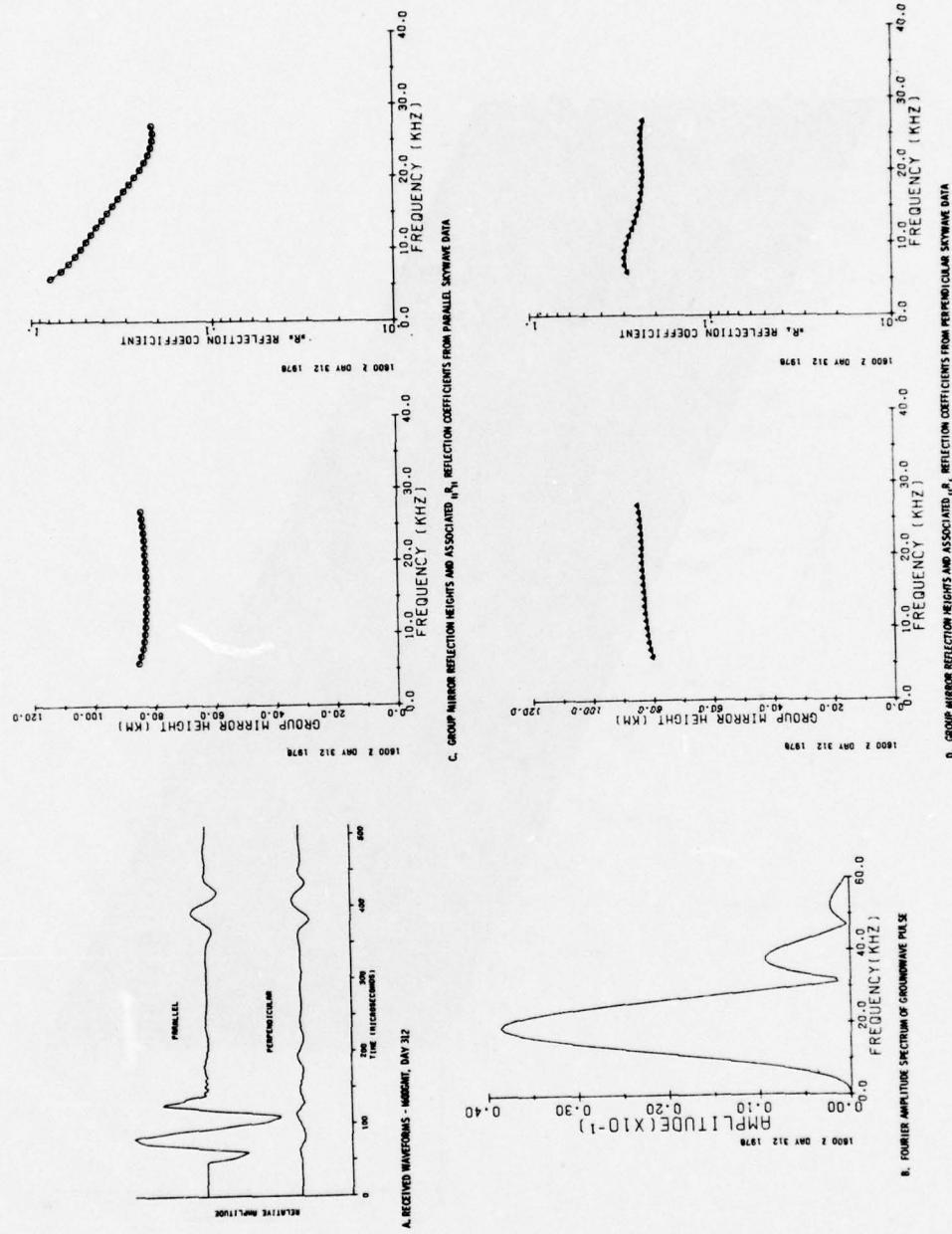


Figure 12. VL/F/LF Reflectivity Data for the Polar Ionosphere, DAY 309 (5 Nov) - DAY 315 (11 Nov) 1978

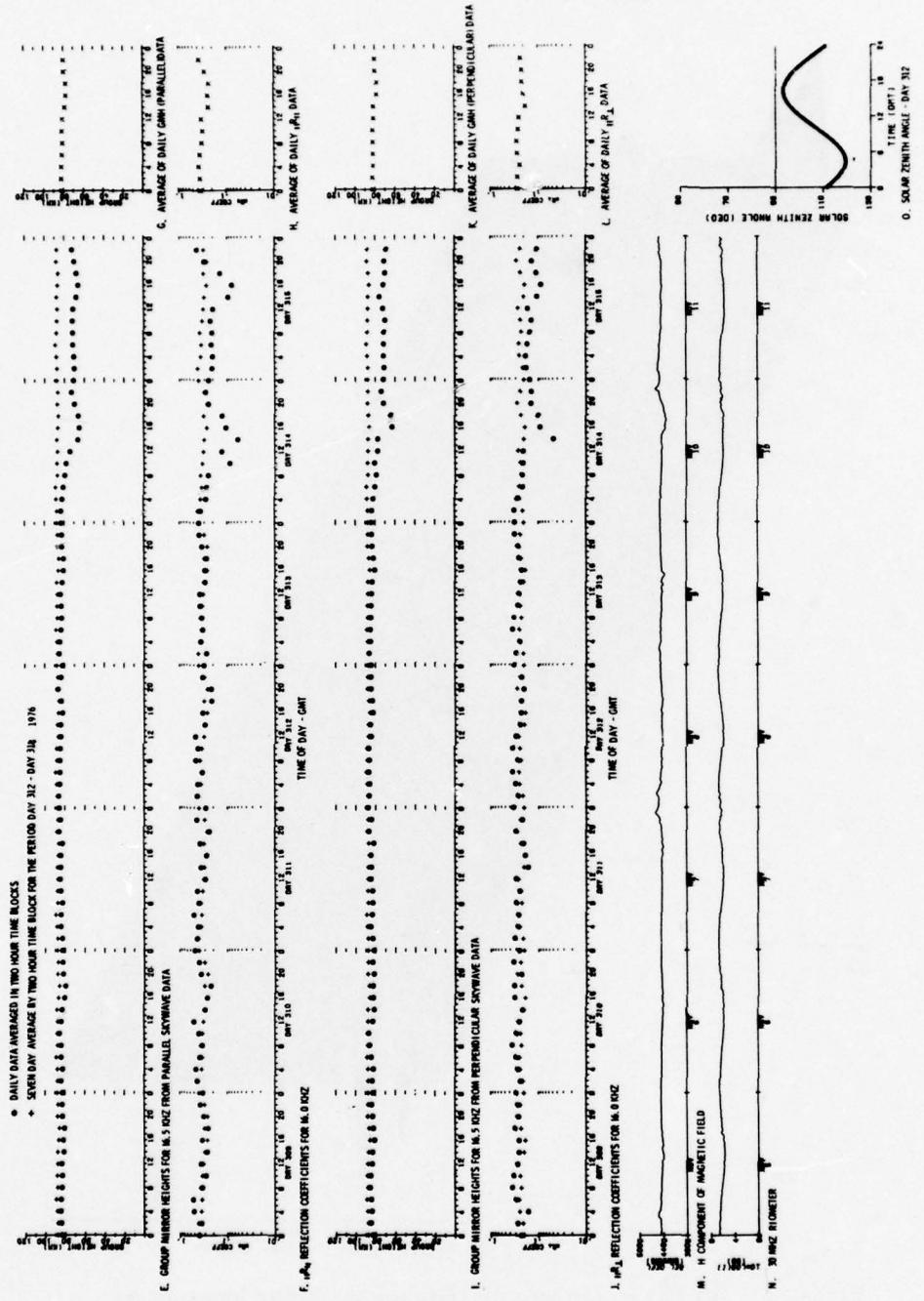


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 309 (5 Nov) - DAY 315 (11 Nov) 1978 (Cont.)

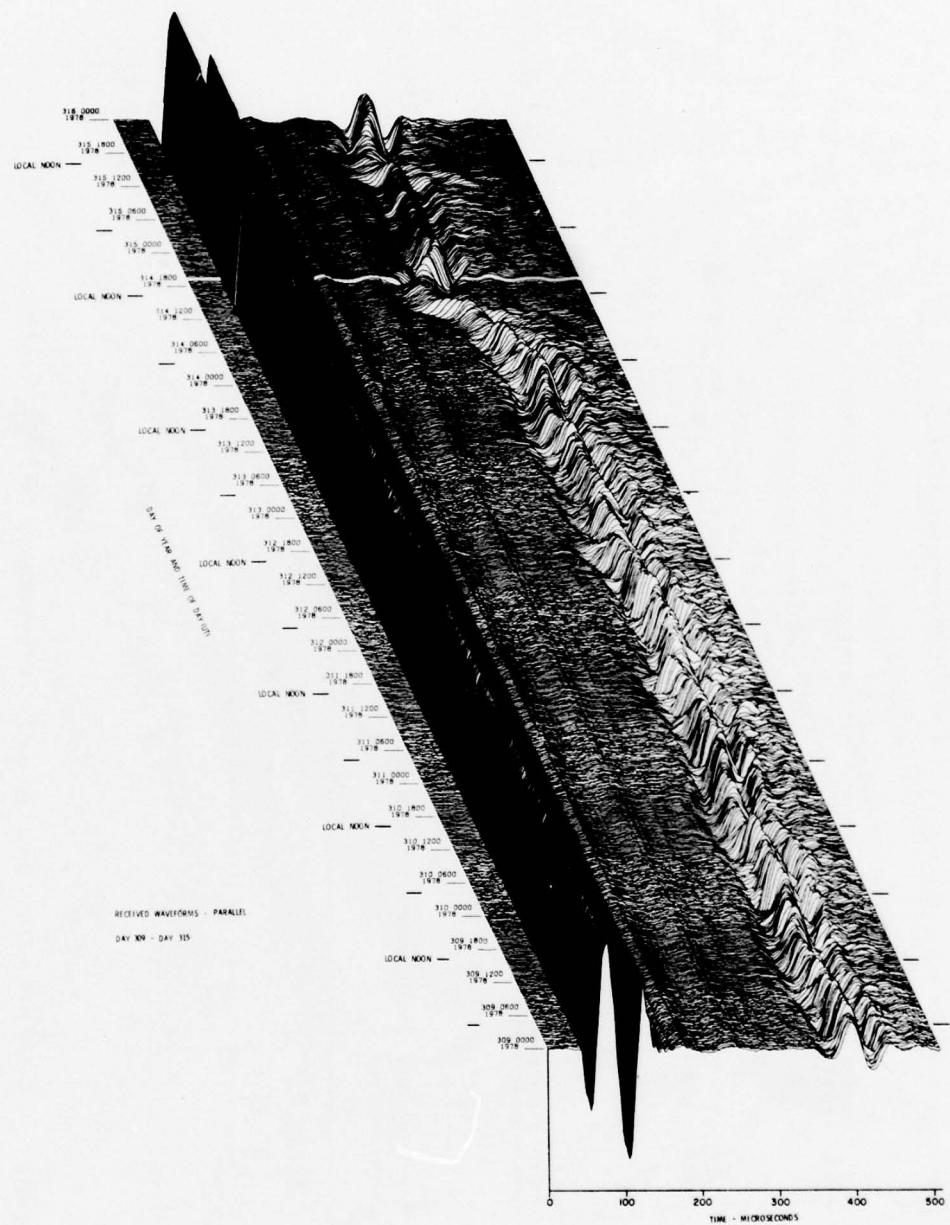


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere,  
DAY 309 (5 Nov) — DAY 315 (11 Nov) 1978 (Cont)  
Part R. II Waveform Display

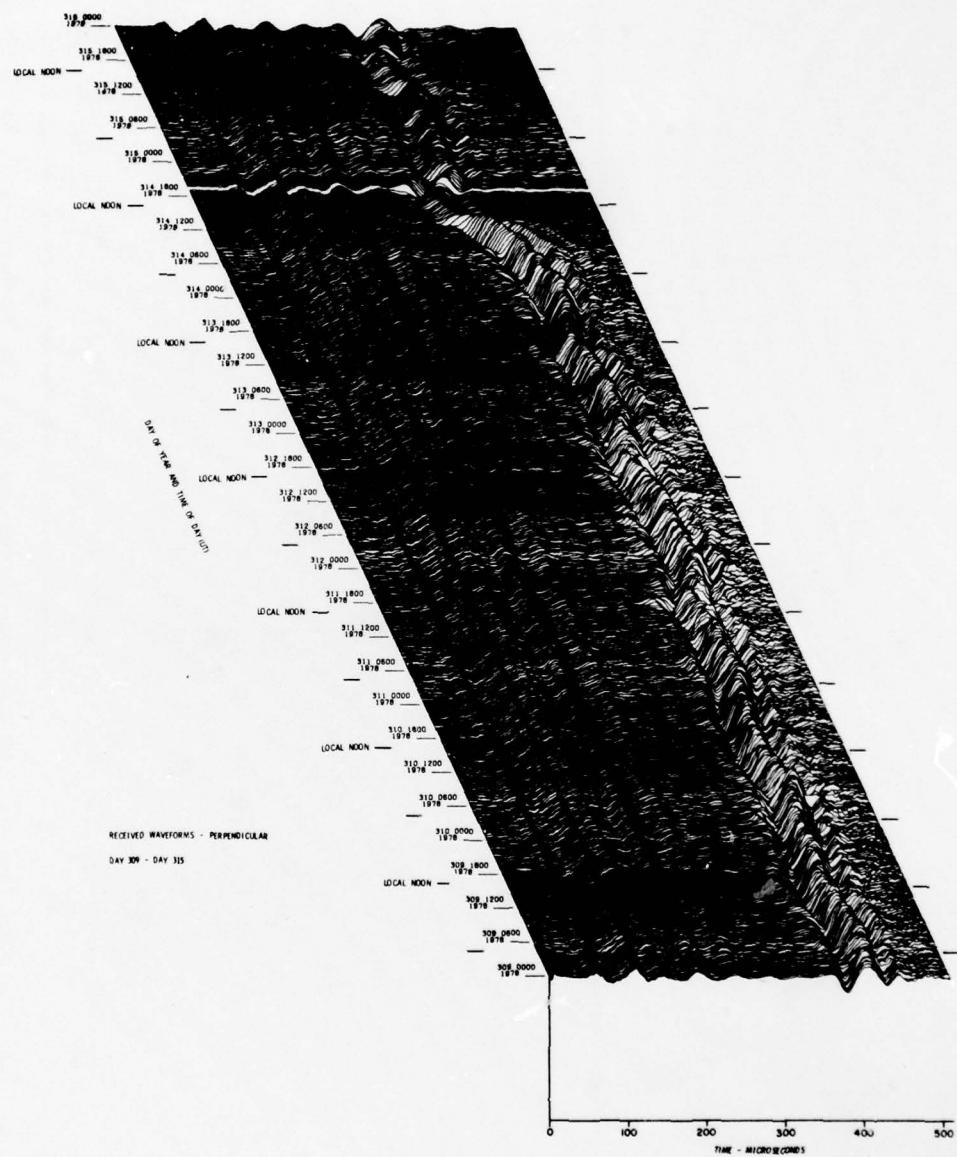


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 309 (5 Nov) - DAY 315 (11 Nov) 1978 (Cont)  
 Part S.  $\perp$  Waveform Display

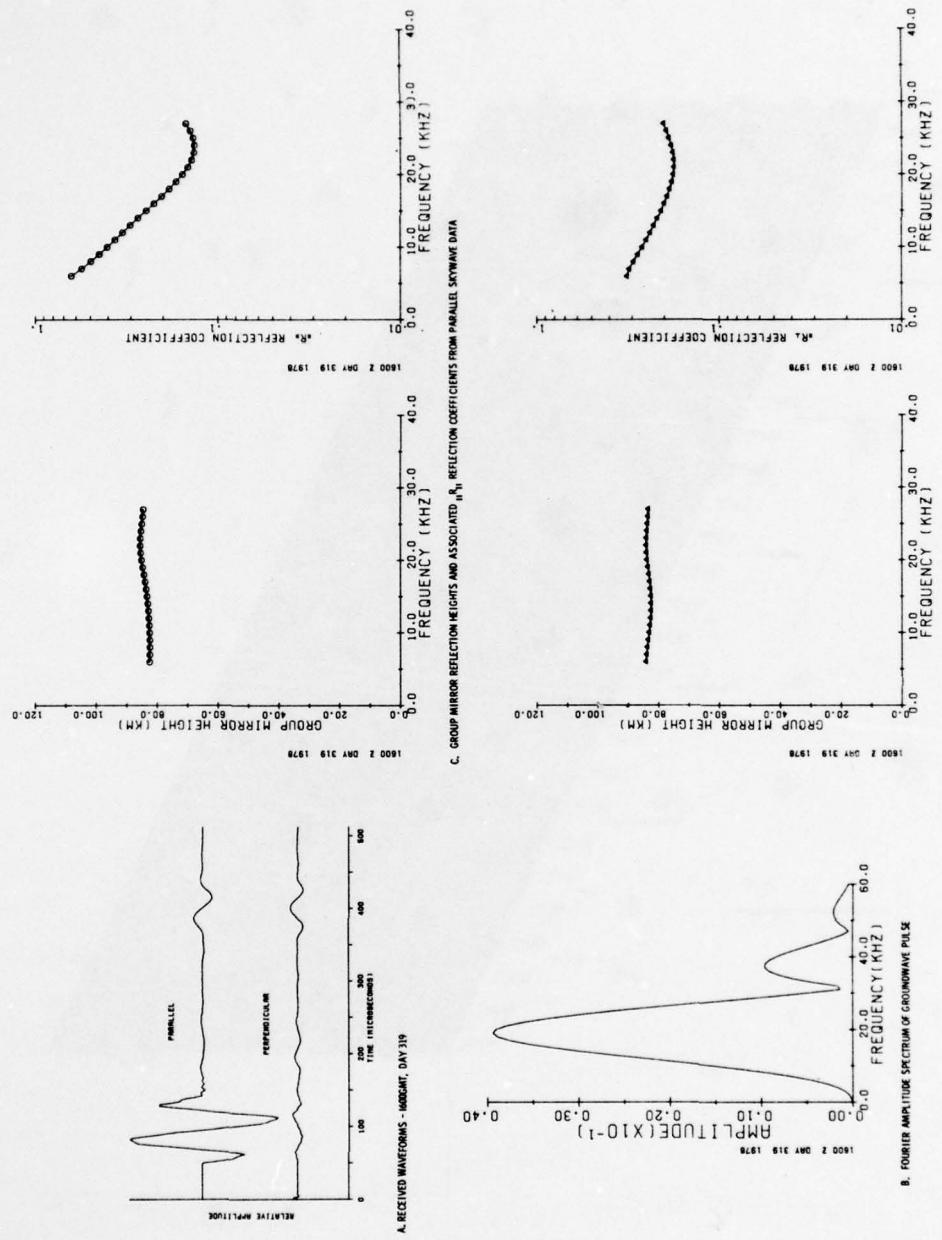


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 316 (12 Nov) — DAY 322 (18 Nov) 1978

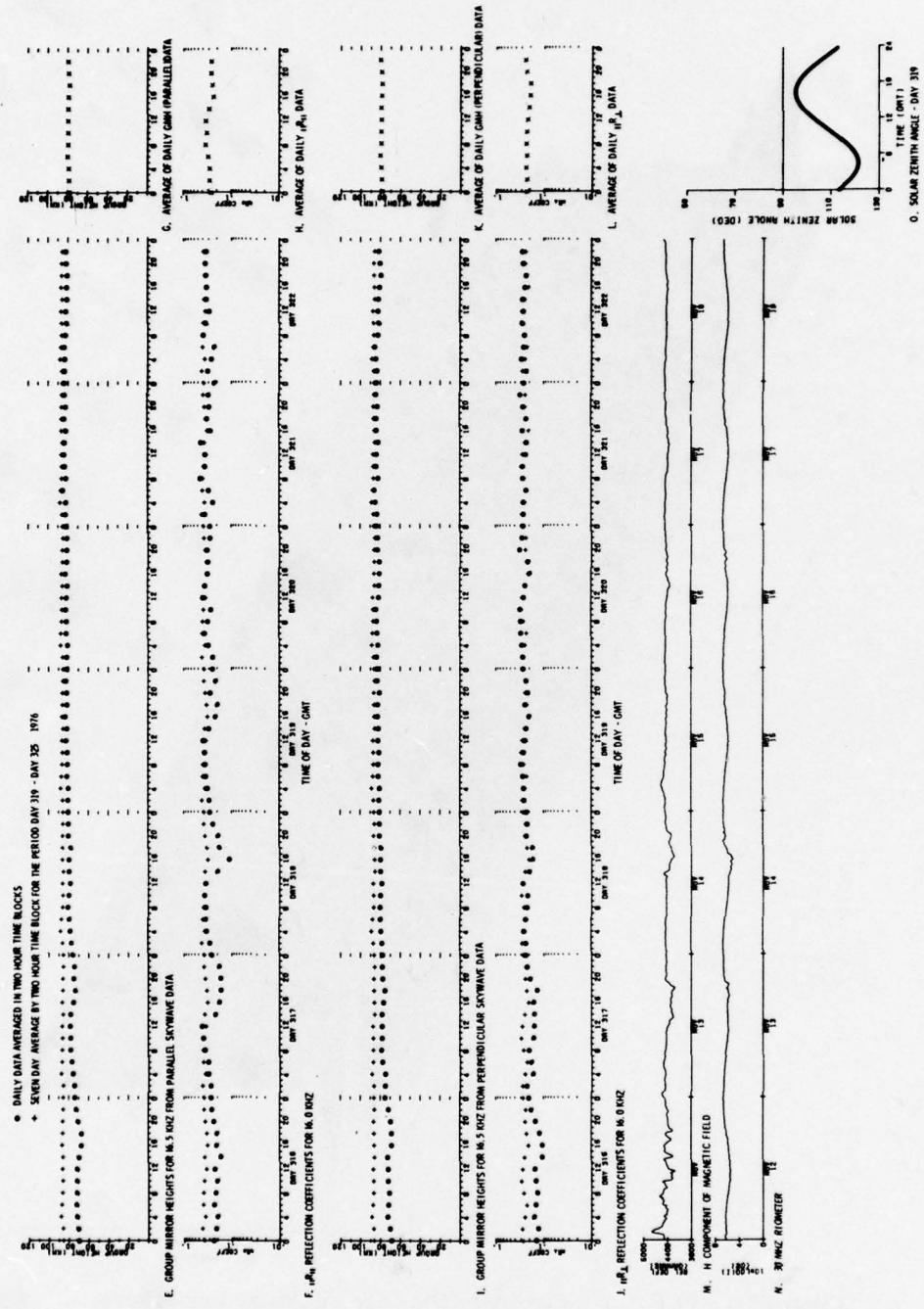


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 316 (12 Nov) - DAY 322 (18 Nov) 1976 (Cont)

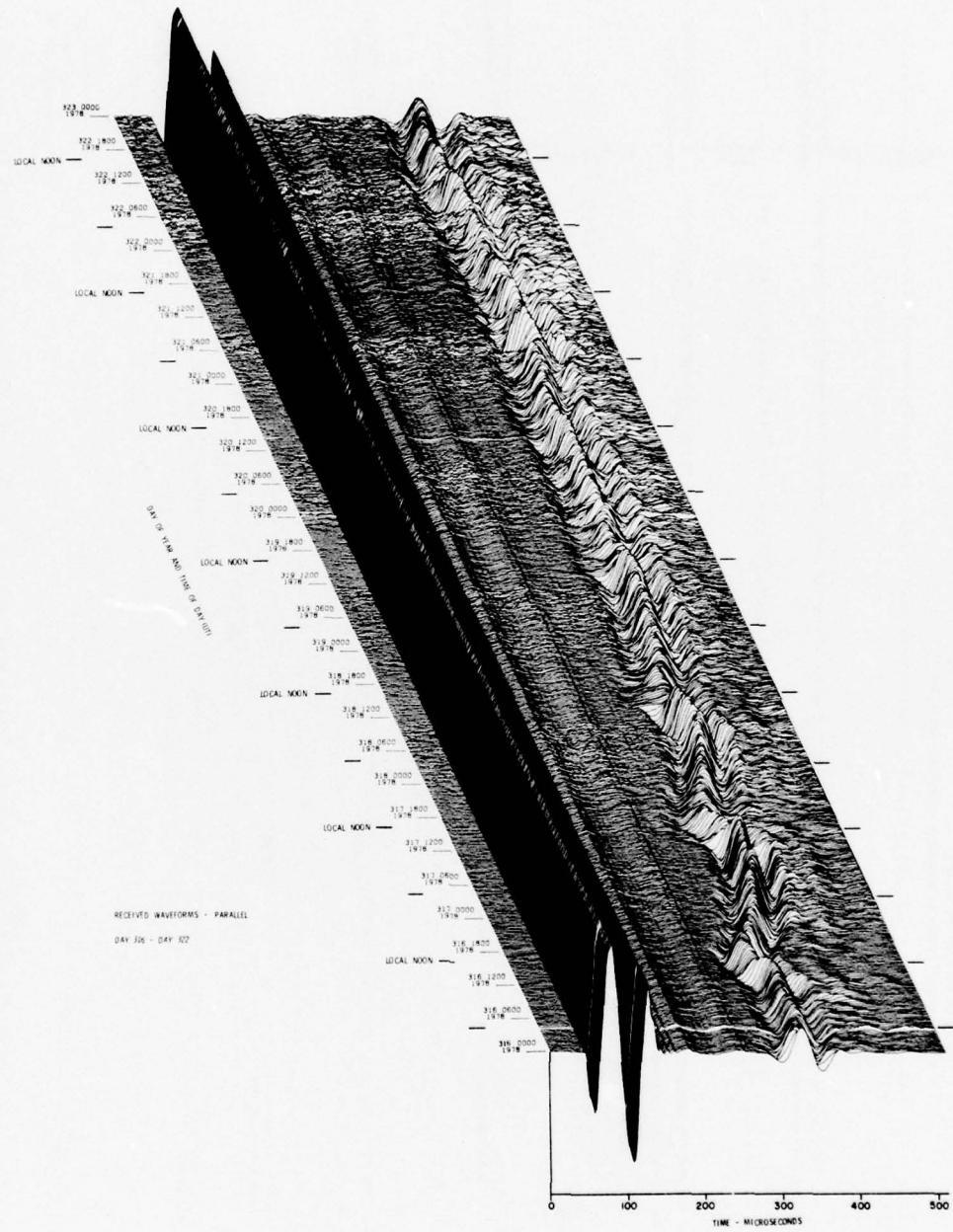


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 316 (12 Nov) - DAY 322 (18 Nov) 1978 (Cont)  
 Part R. II Waveform Display

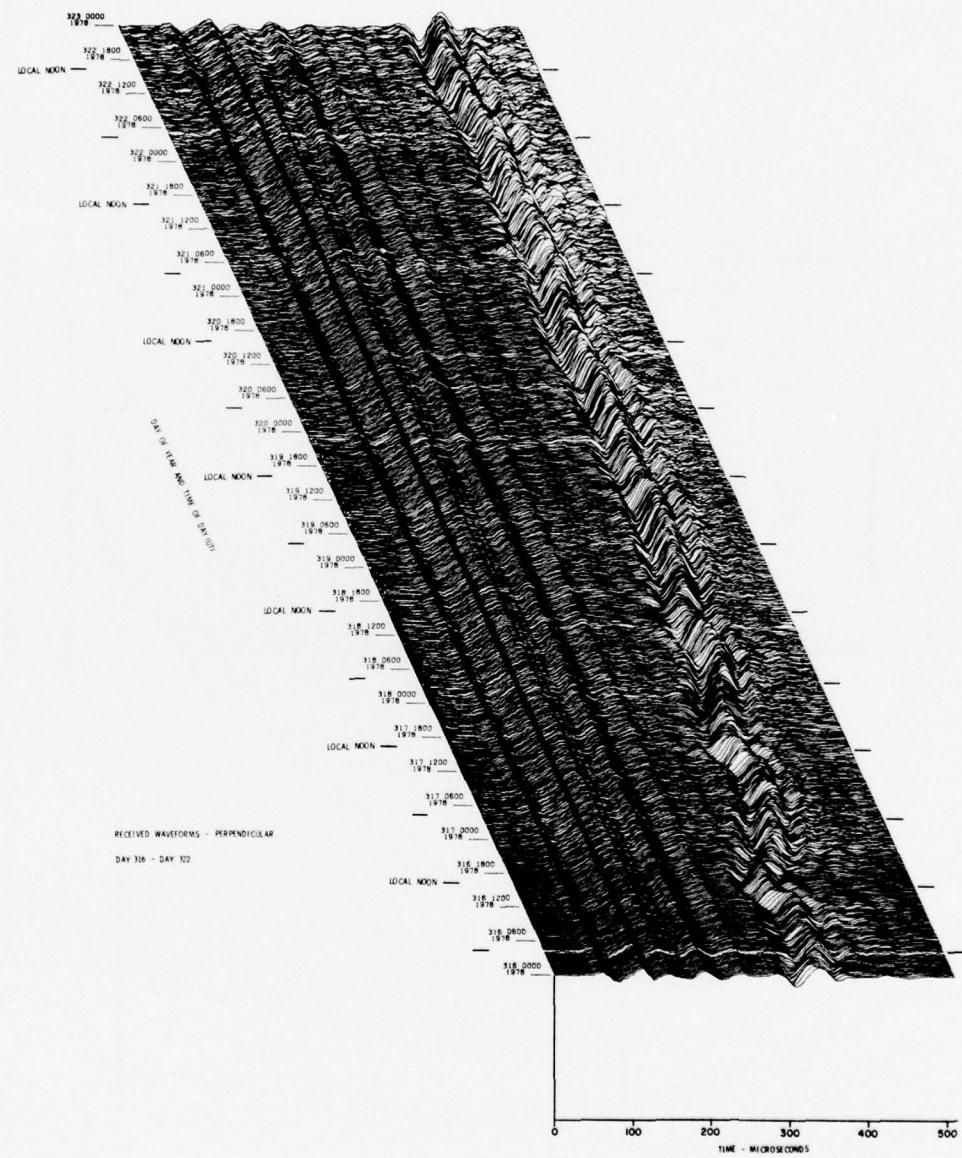


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 316 (12 Nov) - DAY 322 (18 Nov) 1978 (Cont)  
 Part S.  $\perp$  Waveform Display

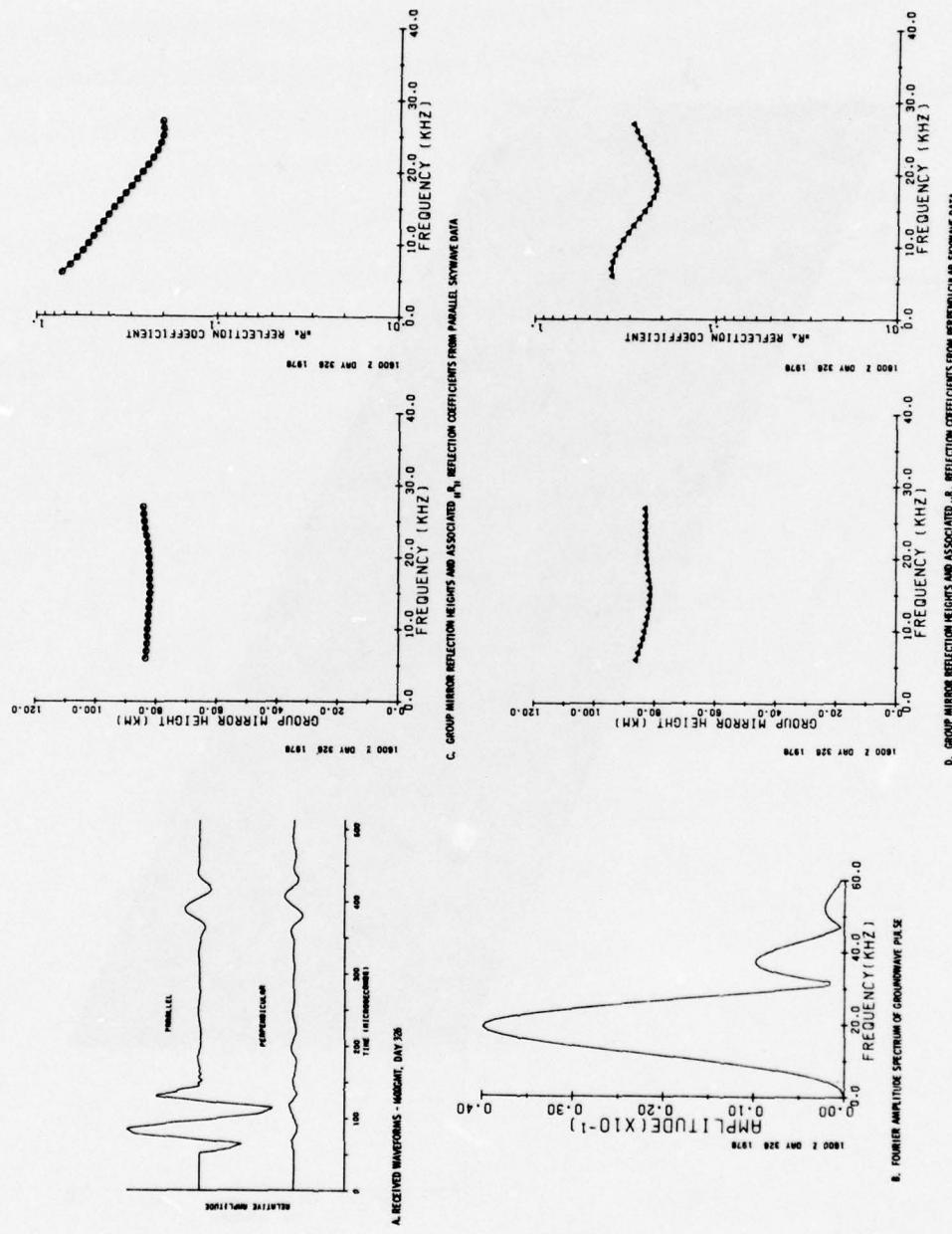


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 323 (19 Nov) – DAY 329 (25 Nov) 1978

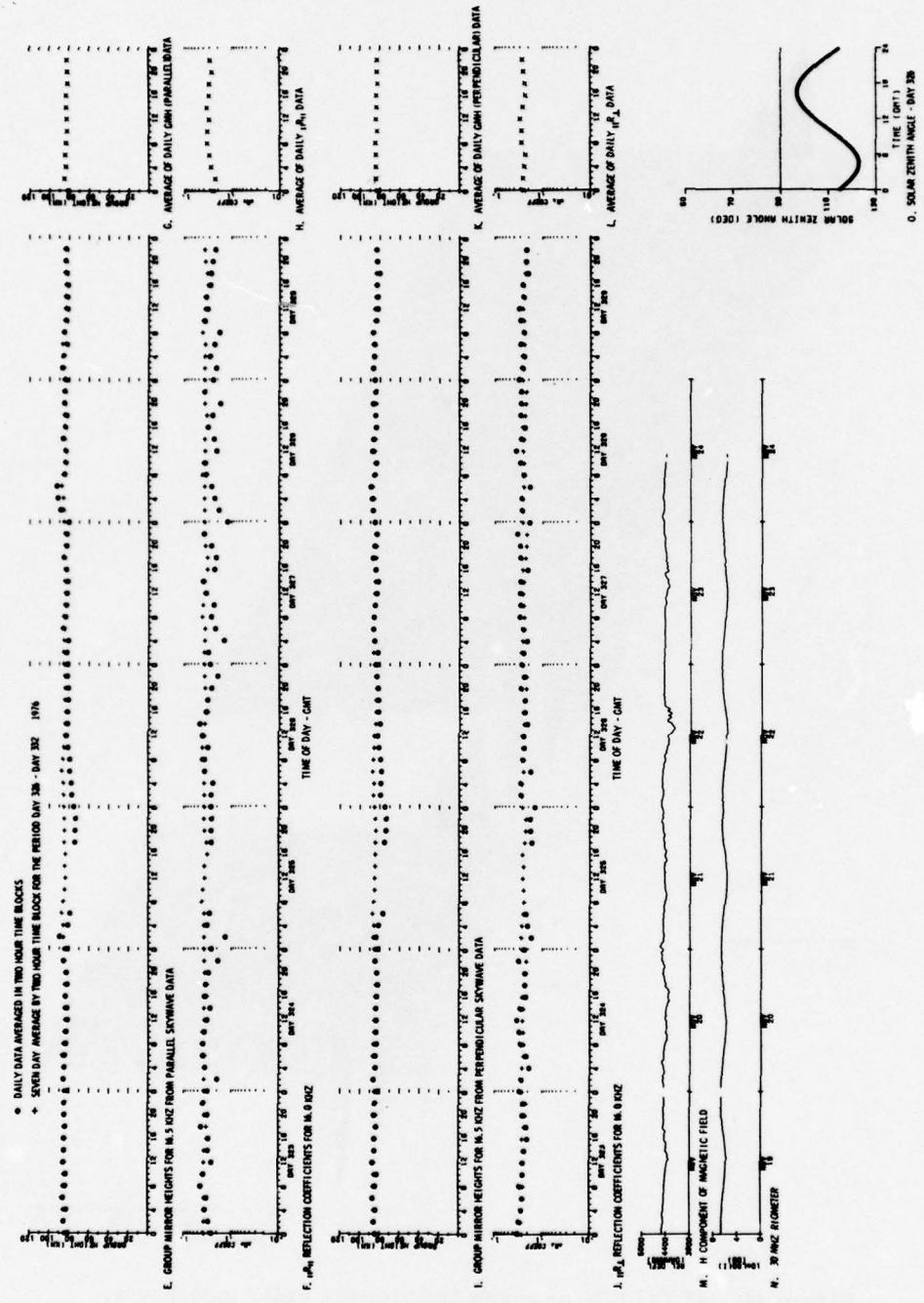


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 323 (19 Nov) — DAY 329 (25 Nov) 1978 (Cont)

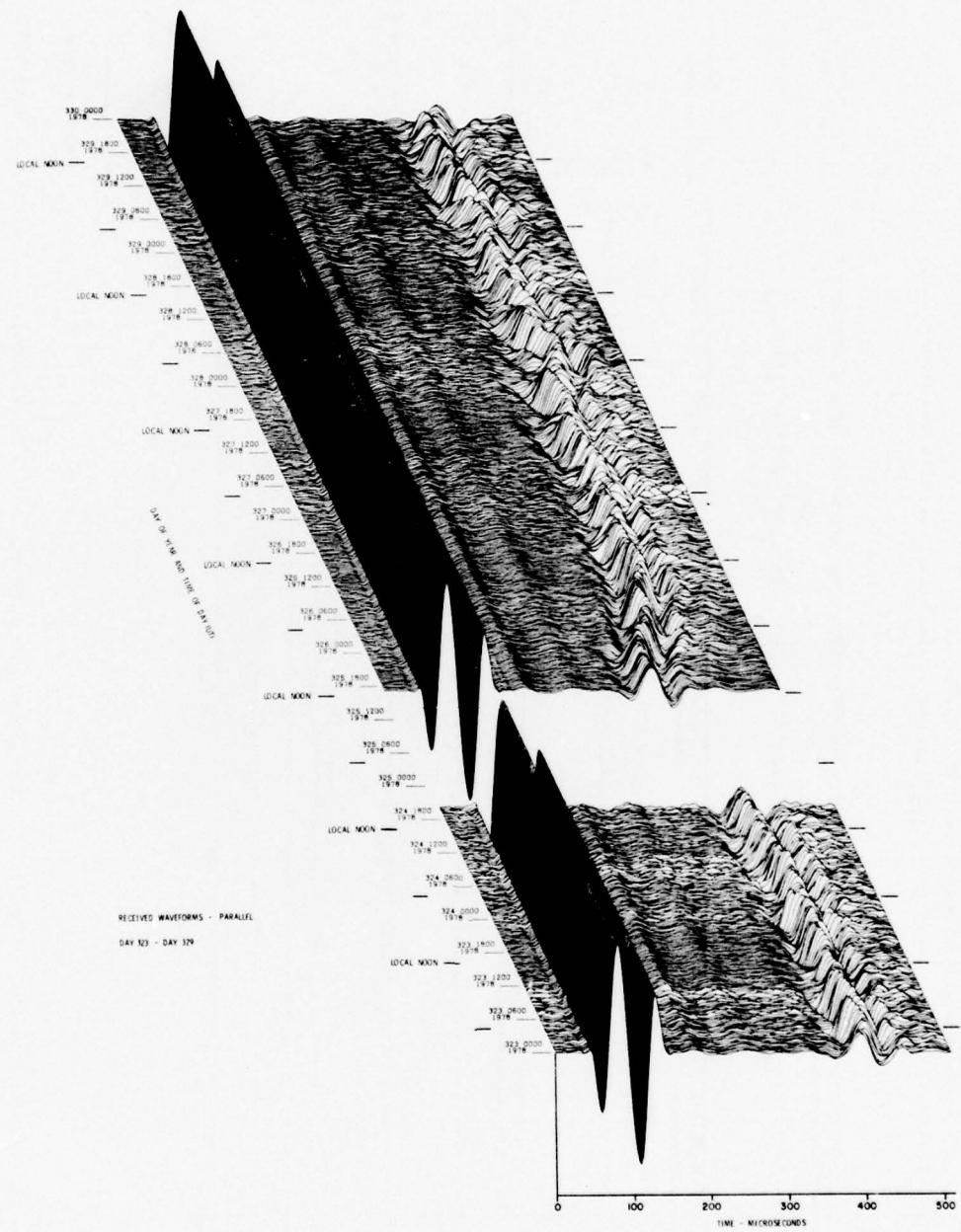


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 323 (19 Nov) - DAY 329 (25 Nov) 1978 (Cont)  
 Part R.  $\parallel$  Waveform Display

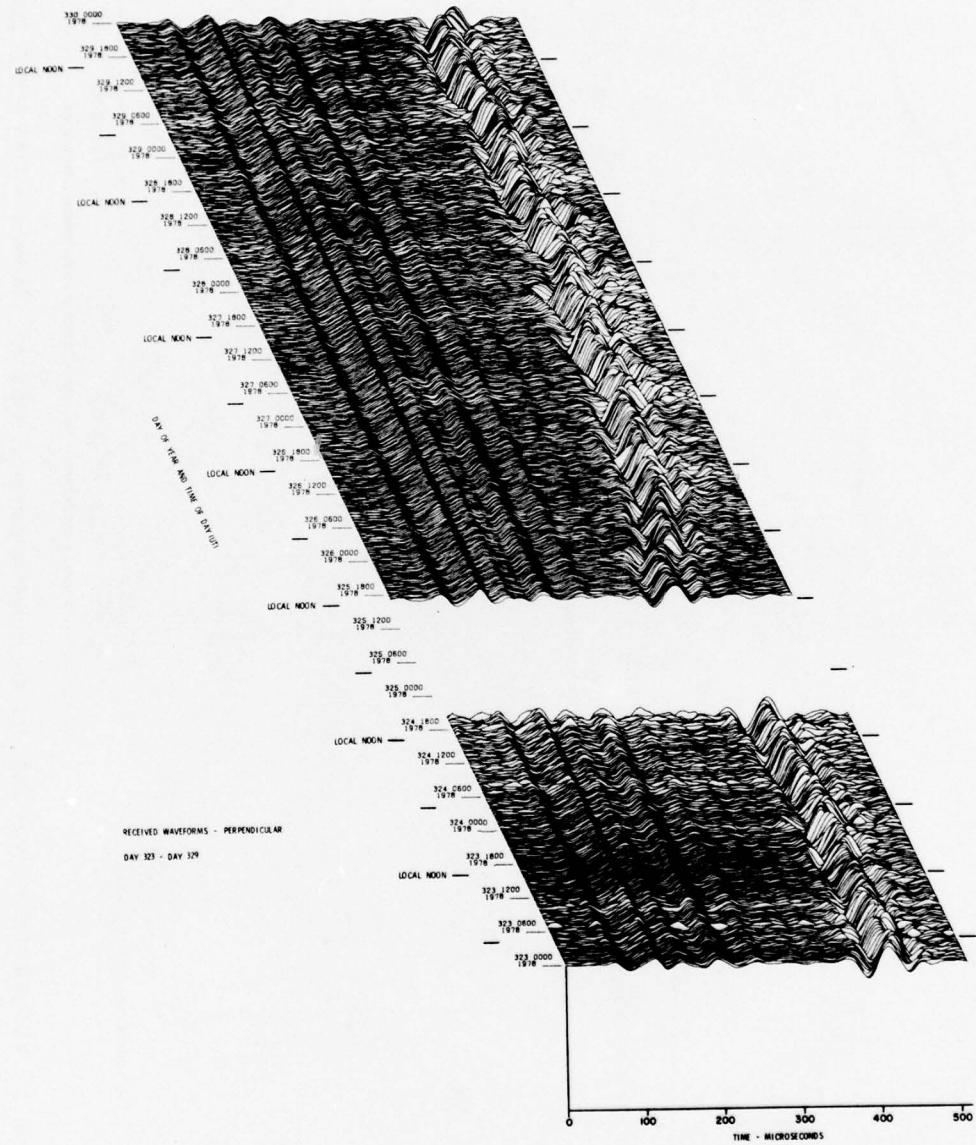


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere,  
DAY 323 (19 Nov) - DAY 329 (25 Nov) 1978 (Cont)  
Part S.  $\perp$  Waveform Display

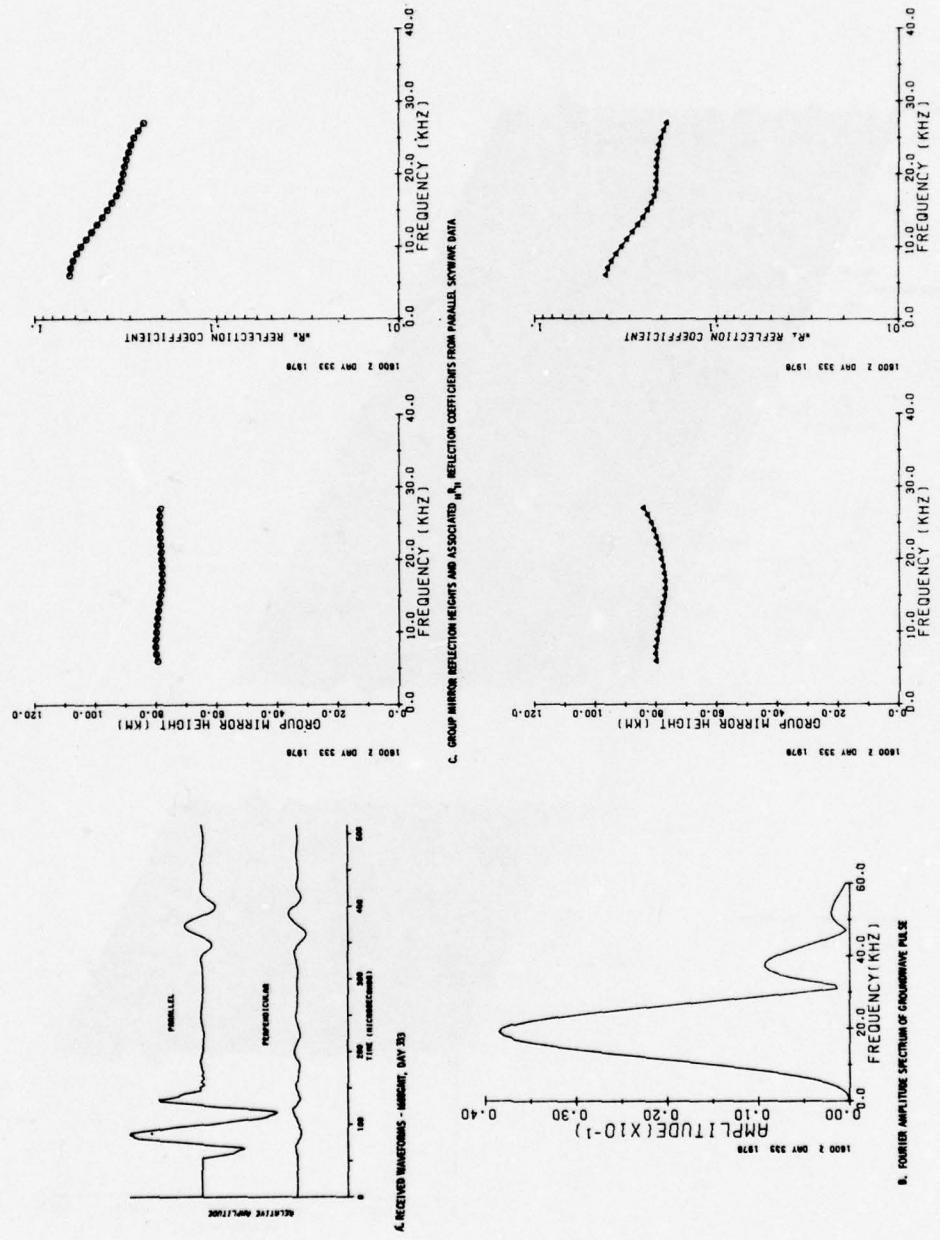


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 330 (26 Nov) — DAY 336 (2 Dec) 1978

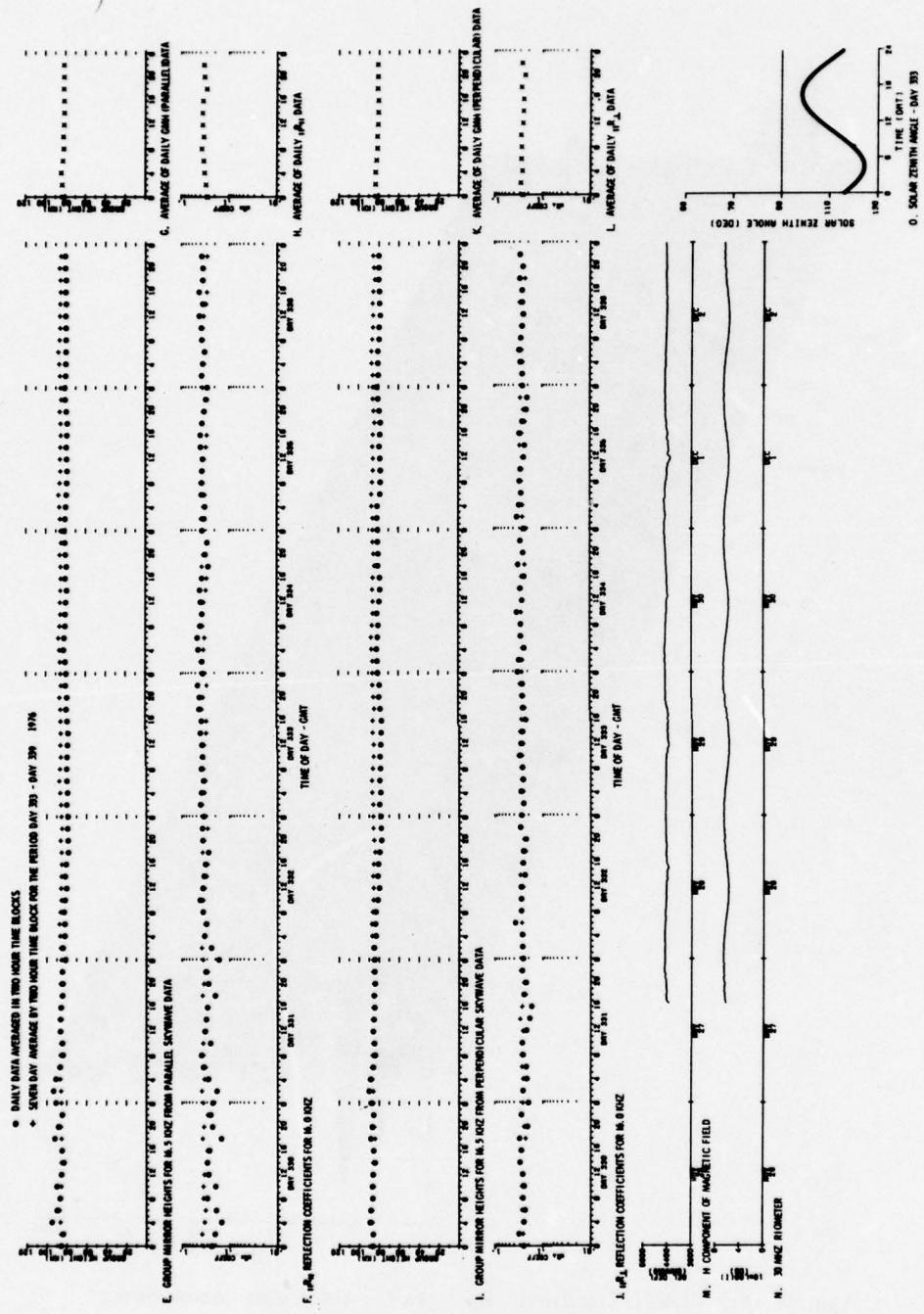


Figure 15. VL/F/LF Reflectivity Data for the Polar Ionosphere, DAY 330 (26 Nov) — DAY 336 (2 Dec) 1978 (Cont)

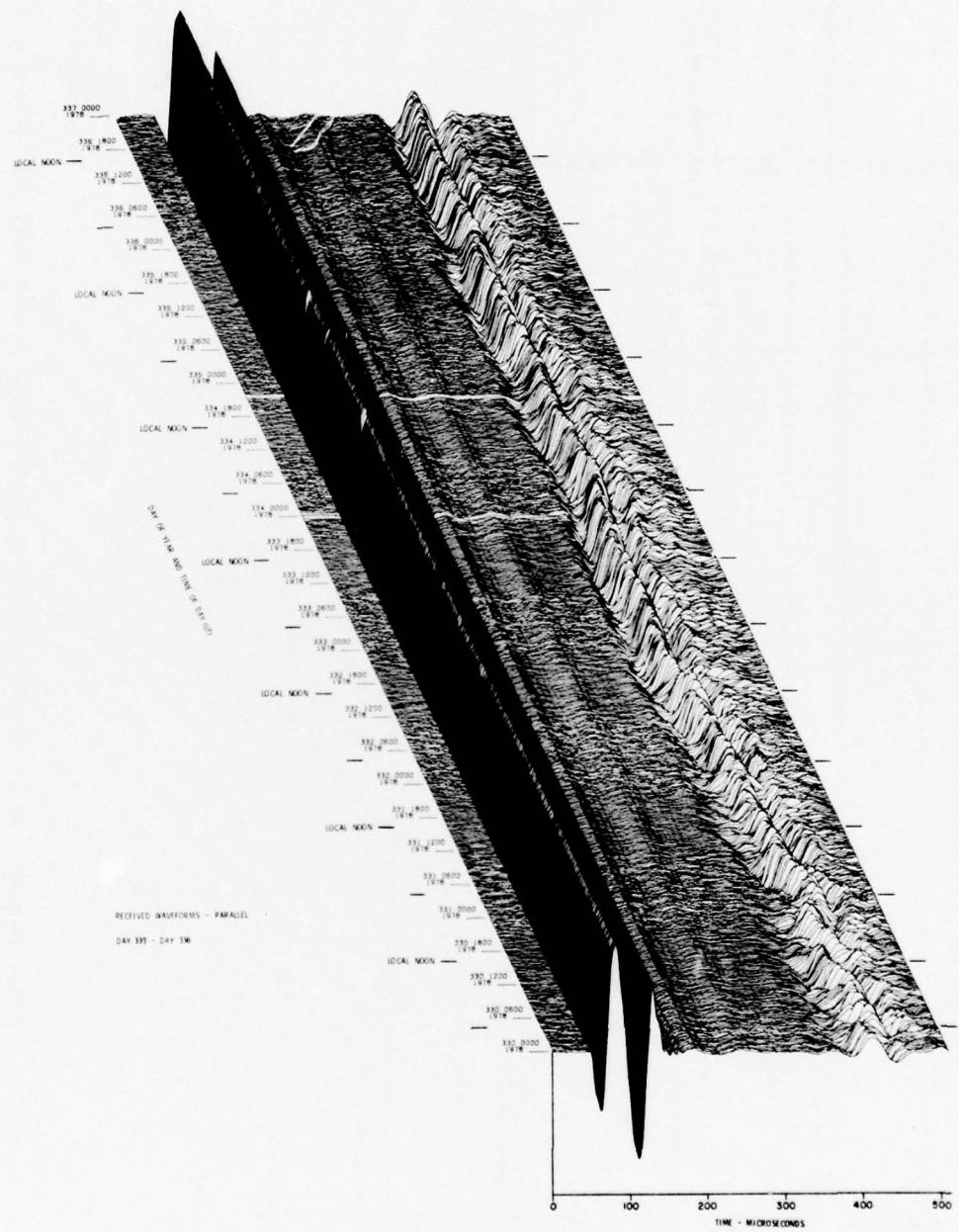


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 330 (26 Nov) – DAY 336 (2 Dec) 1978 (Cont)  
 Part R. II Waveform Display

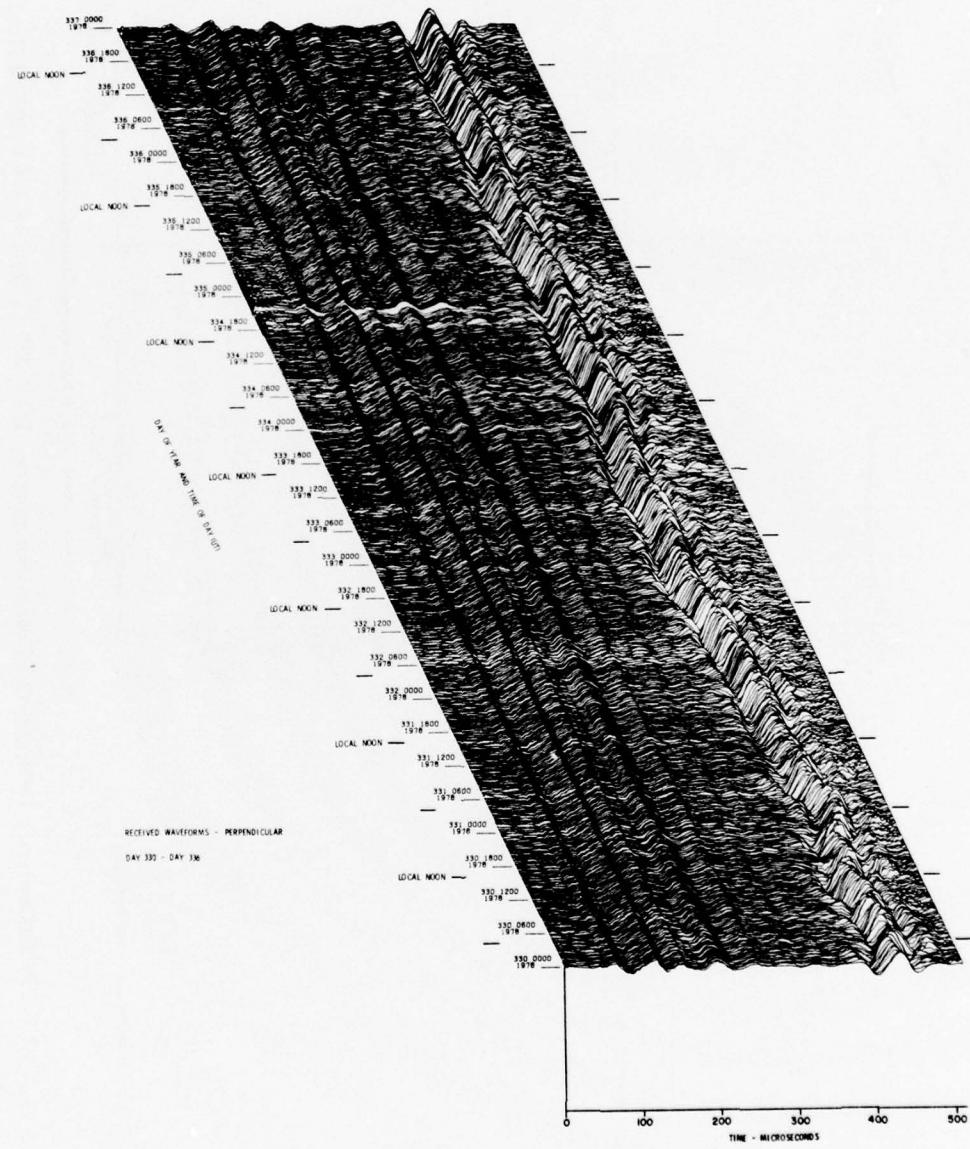


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 330 (26 Nov) — DAY 336 (2 Dec) 1978 (Cont)  
 Part S.  $\perp$  Waveform Display

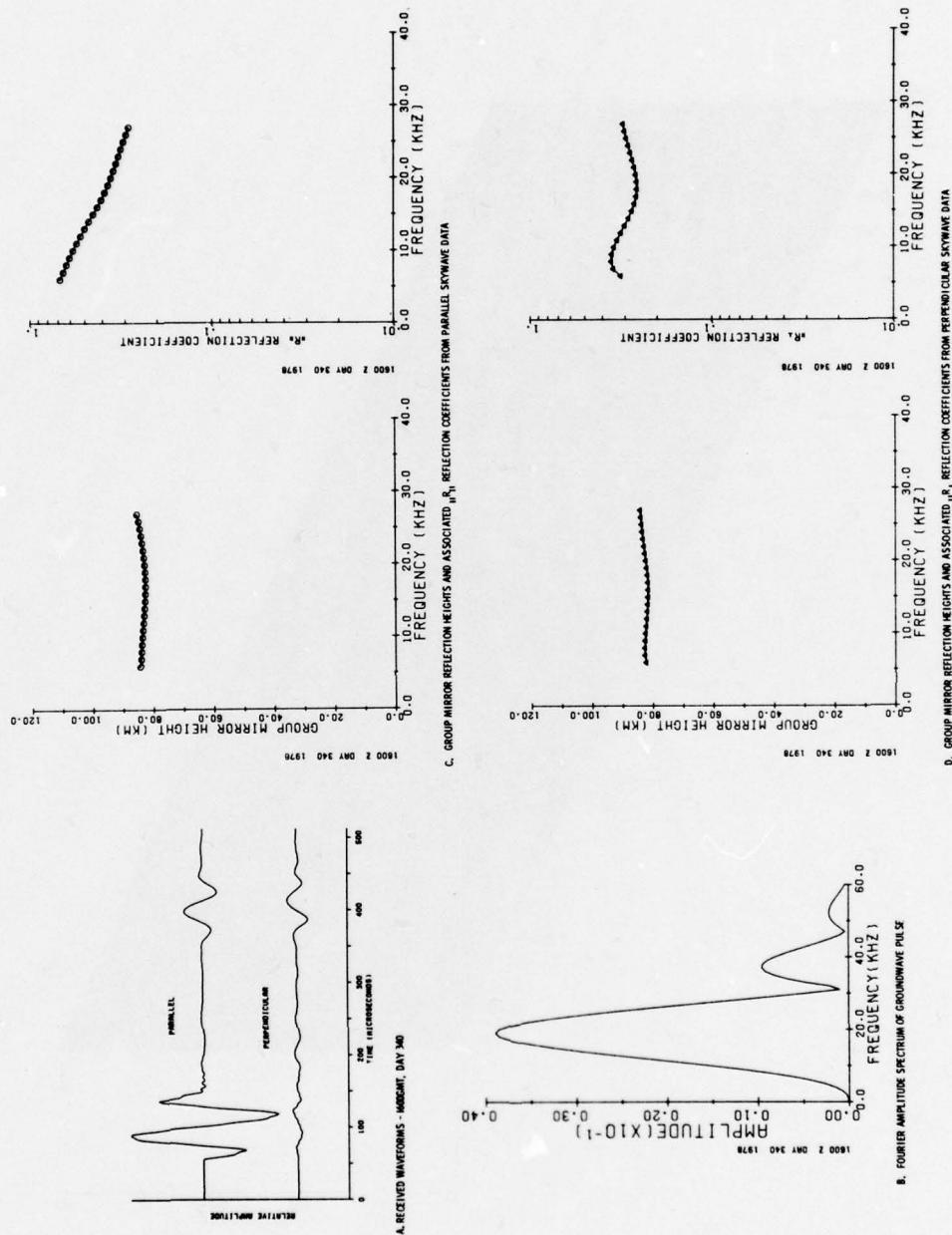


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 337 (3 Dec) - DAY 343 (9 Dec) 1978

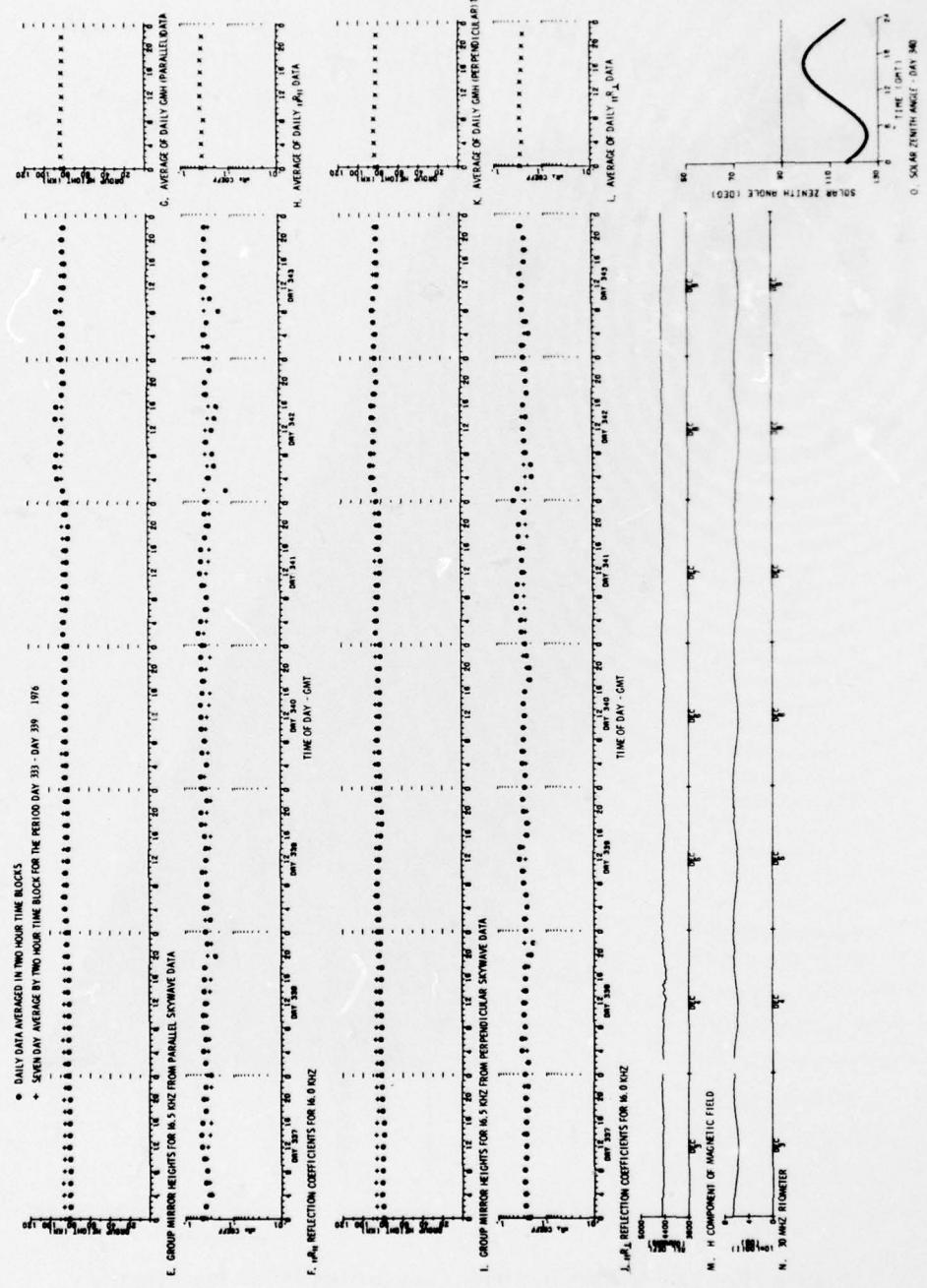


Figure 16. VL/F/LF Reflectivity Data for the Polar Ionosphere, DAY 337 (3 Dec) - DAY 343 (9 Dec) 1978 (Cont)

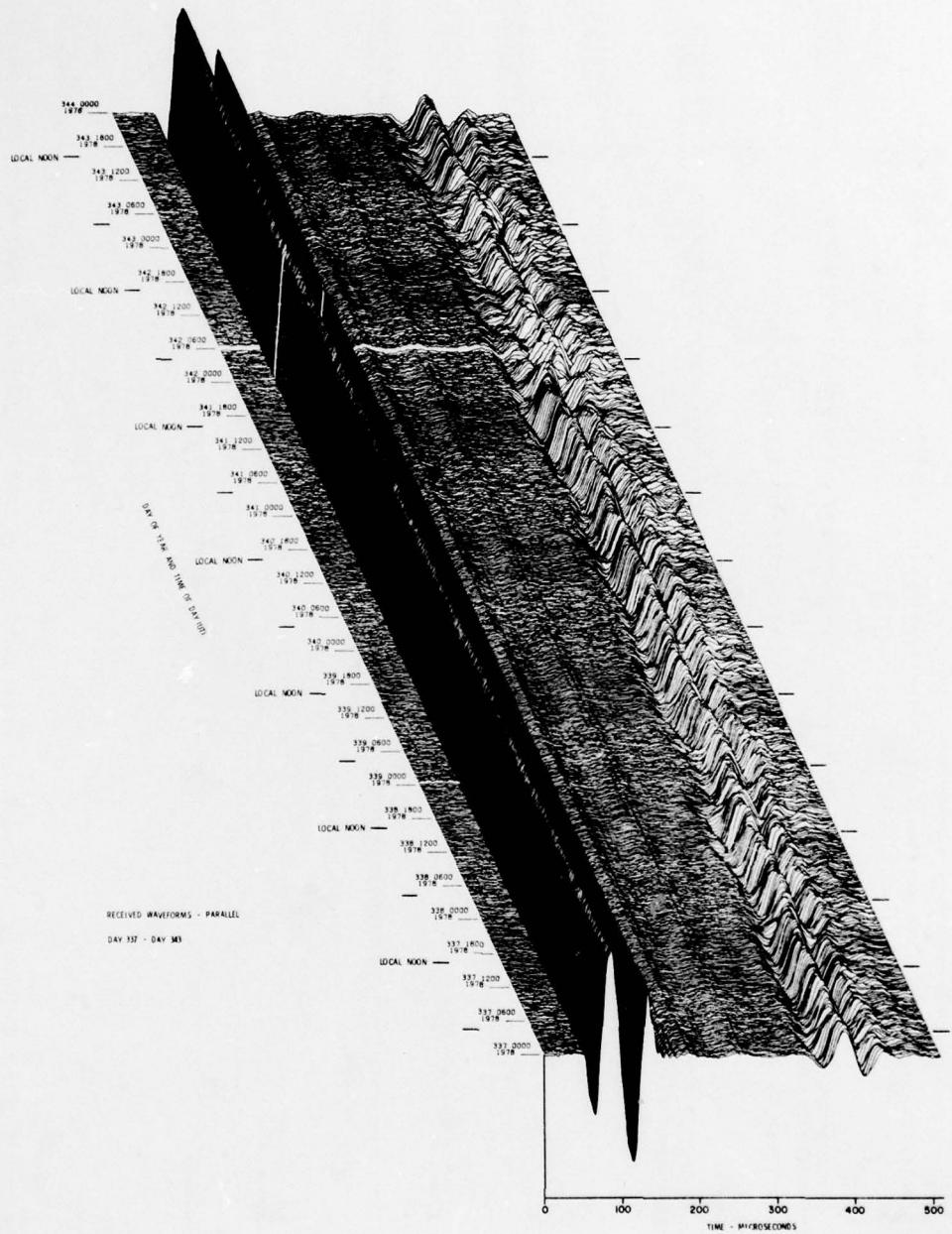


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 337 (3 Dec) — DAY 343 (9 Dec) 1978 (Cont)  
 Part R. II Waveform Display

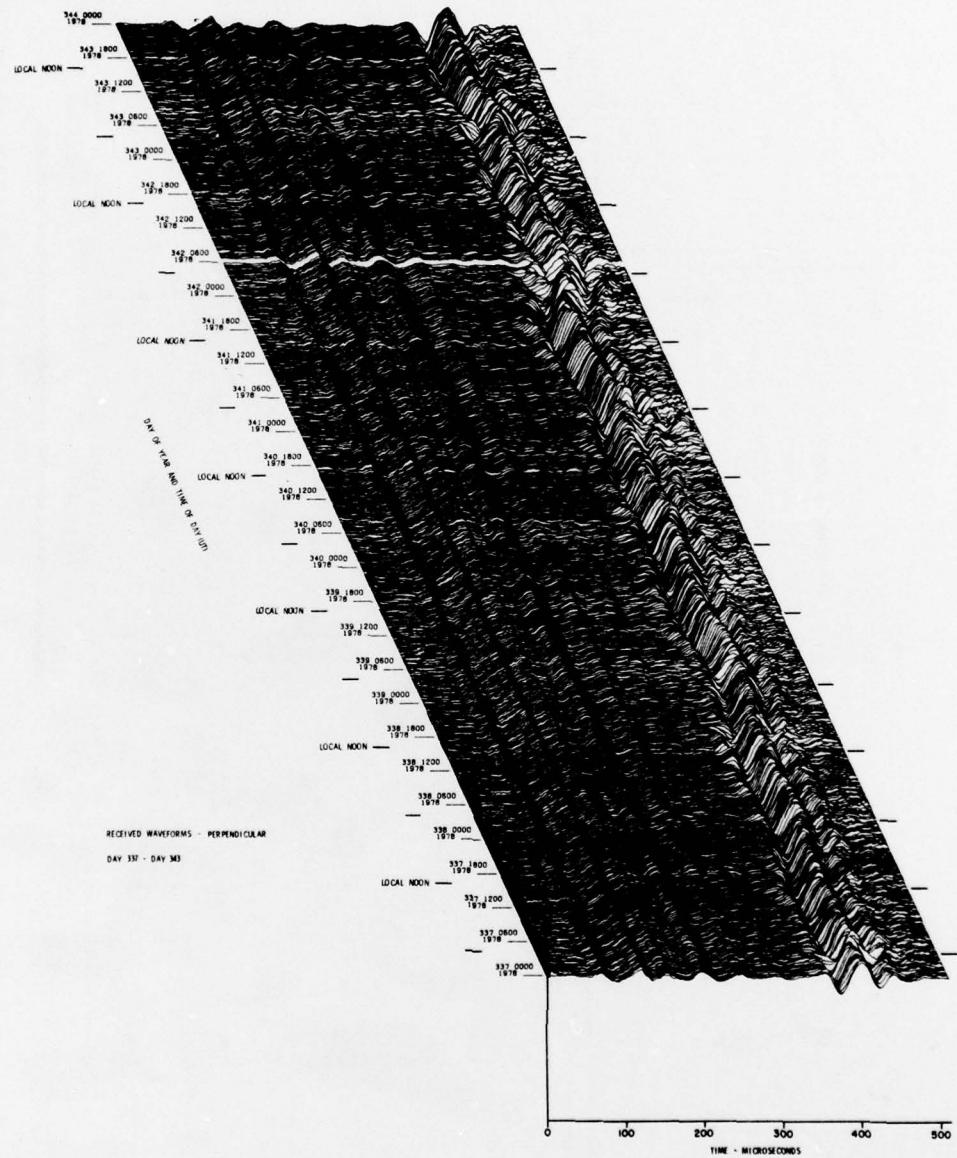


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 337 (3 Dec) — DAY 343 (9 Dec) 1978 (Cont)  
 Part S.  $\perp$  Waveform Display

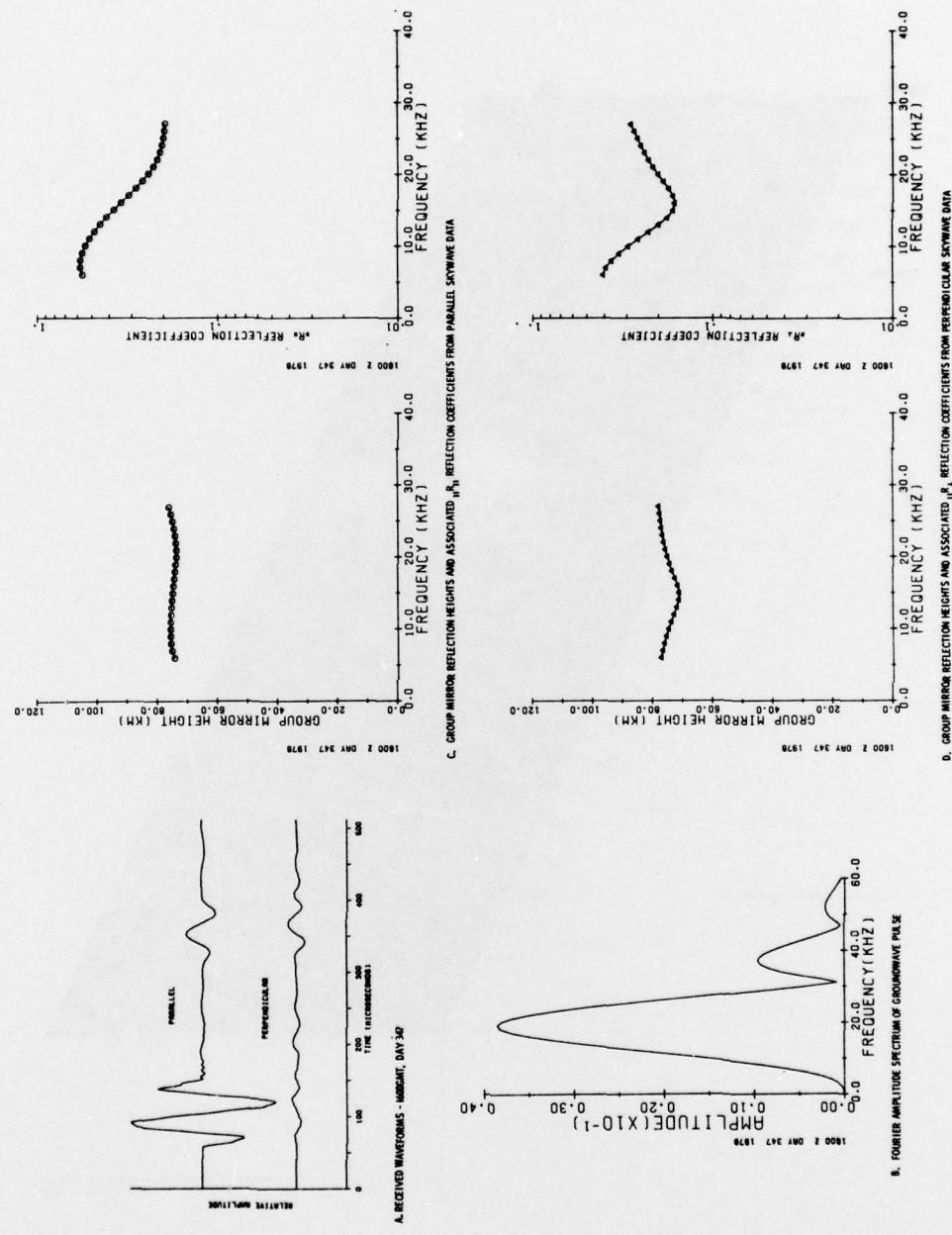


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 344 (10 Dec) — DAY 350 (16 Dec) 1978

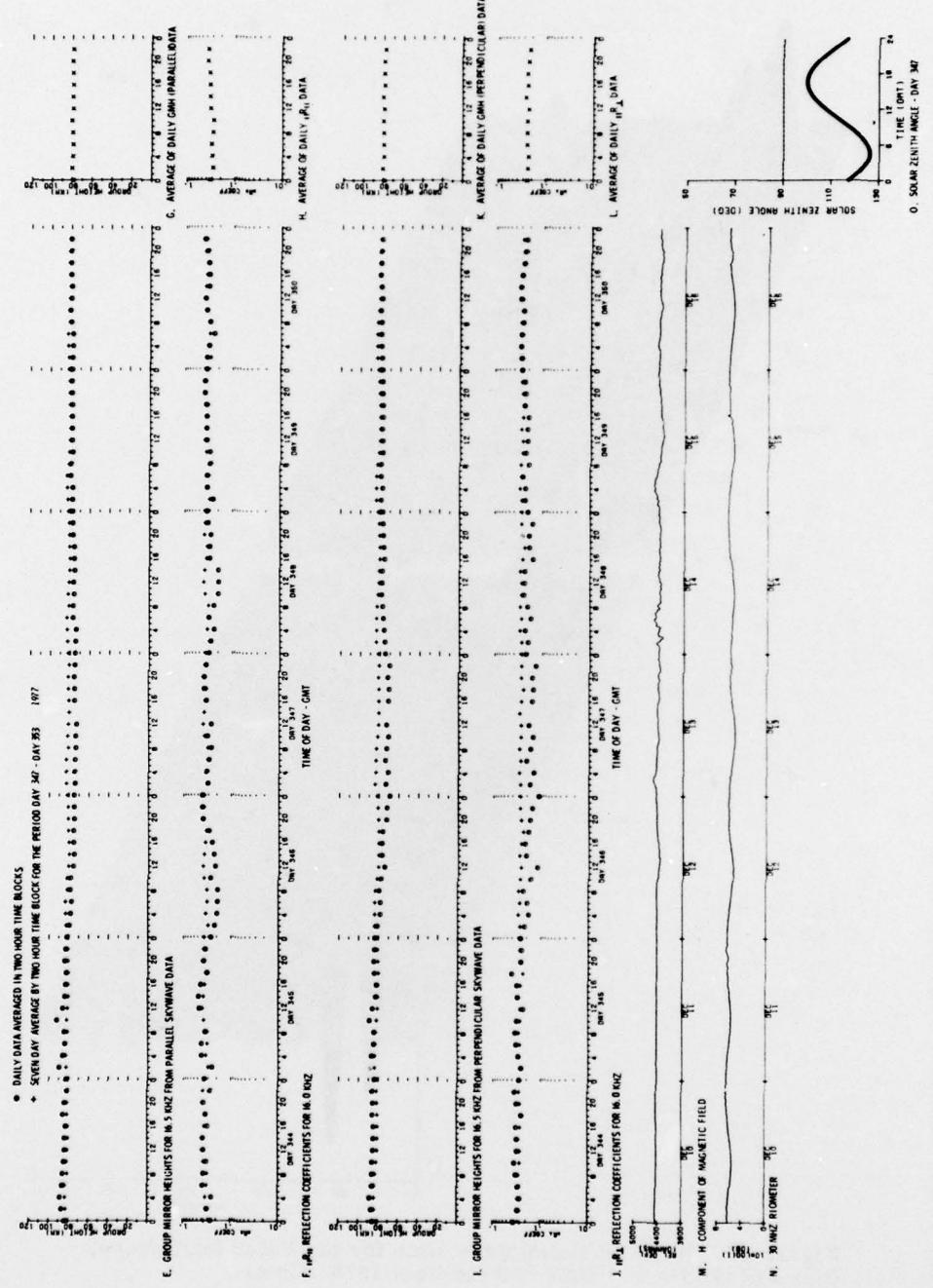


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 344 (10 Dec) - DAY 350 (16 Dec) 1978 (Cont)

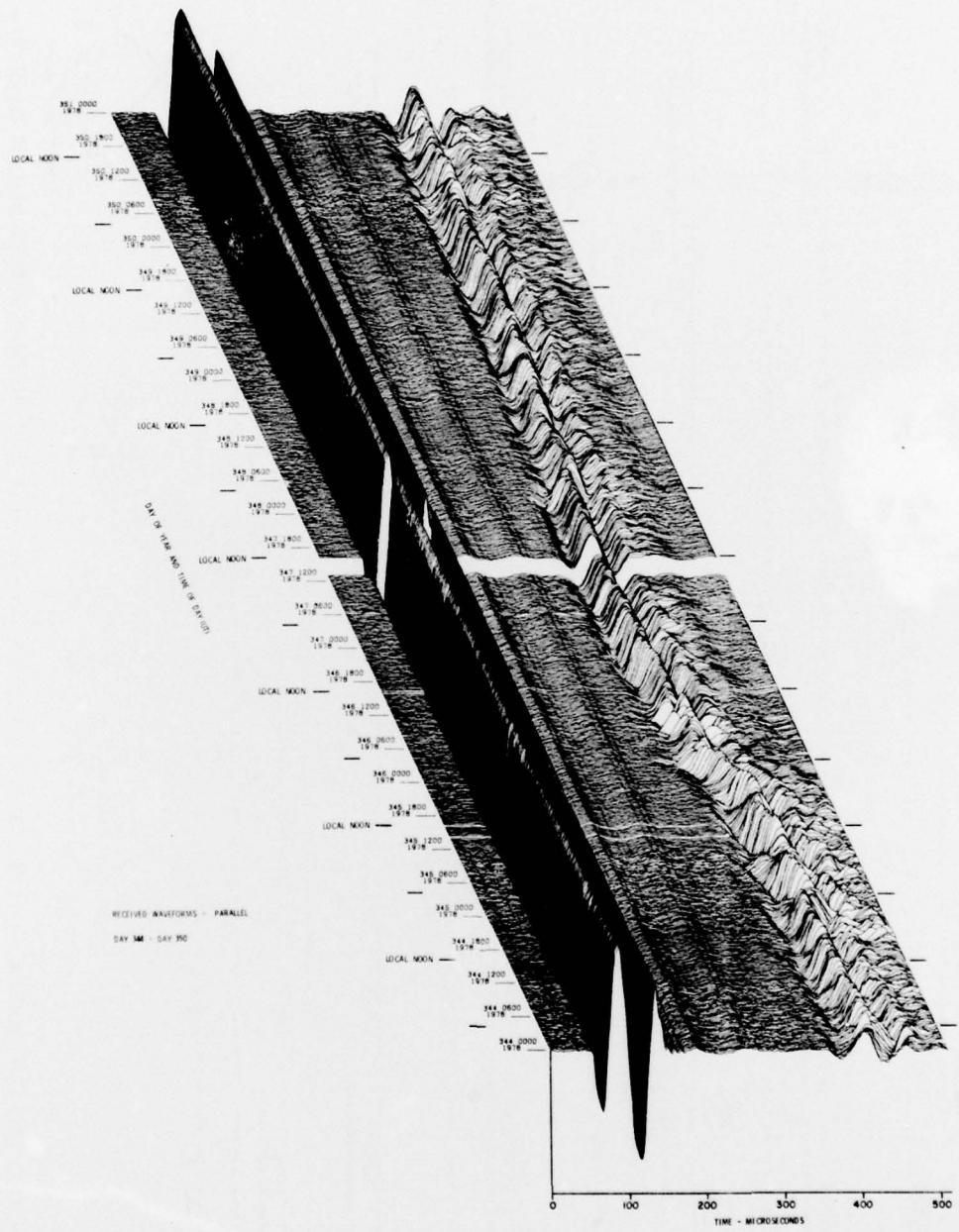


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 344 (10 Dec) - DAY 350 (16 Dec) 1978 (Cont)  
 Part R. II Waveform Display

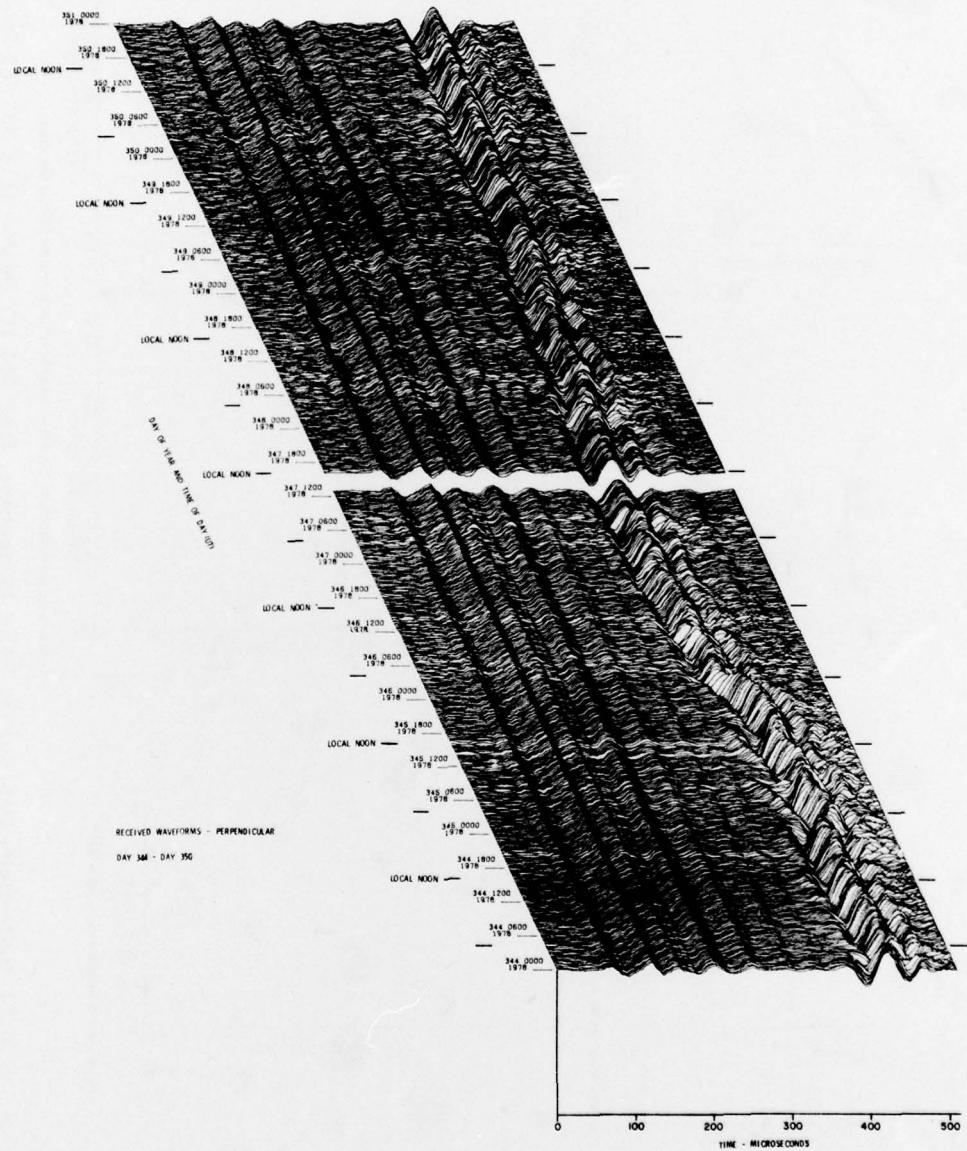


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere,  
DAY 344 (10 Dec) — DAY 350 (16 Dec) 1978 (Cont)  
Part S.  $\perp$  Waveform Display

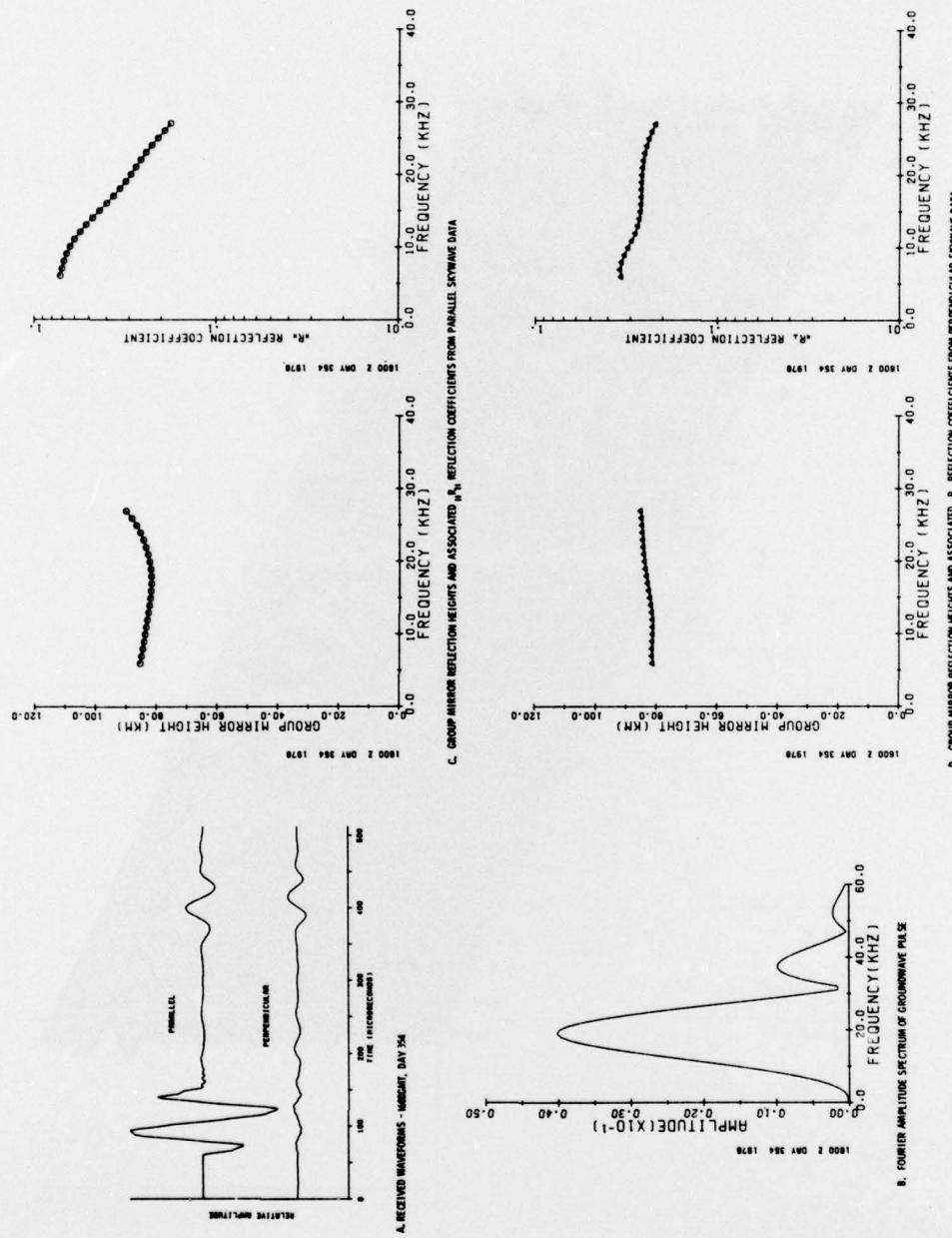


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 351 (17 Dec) – DAY 357 (23 Dec) 1978

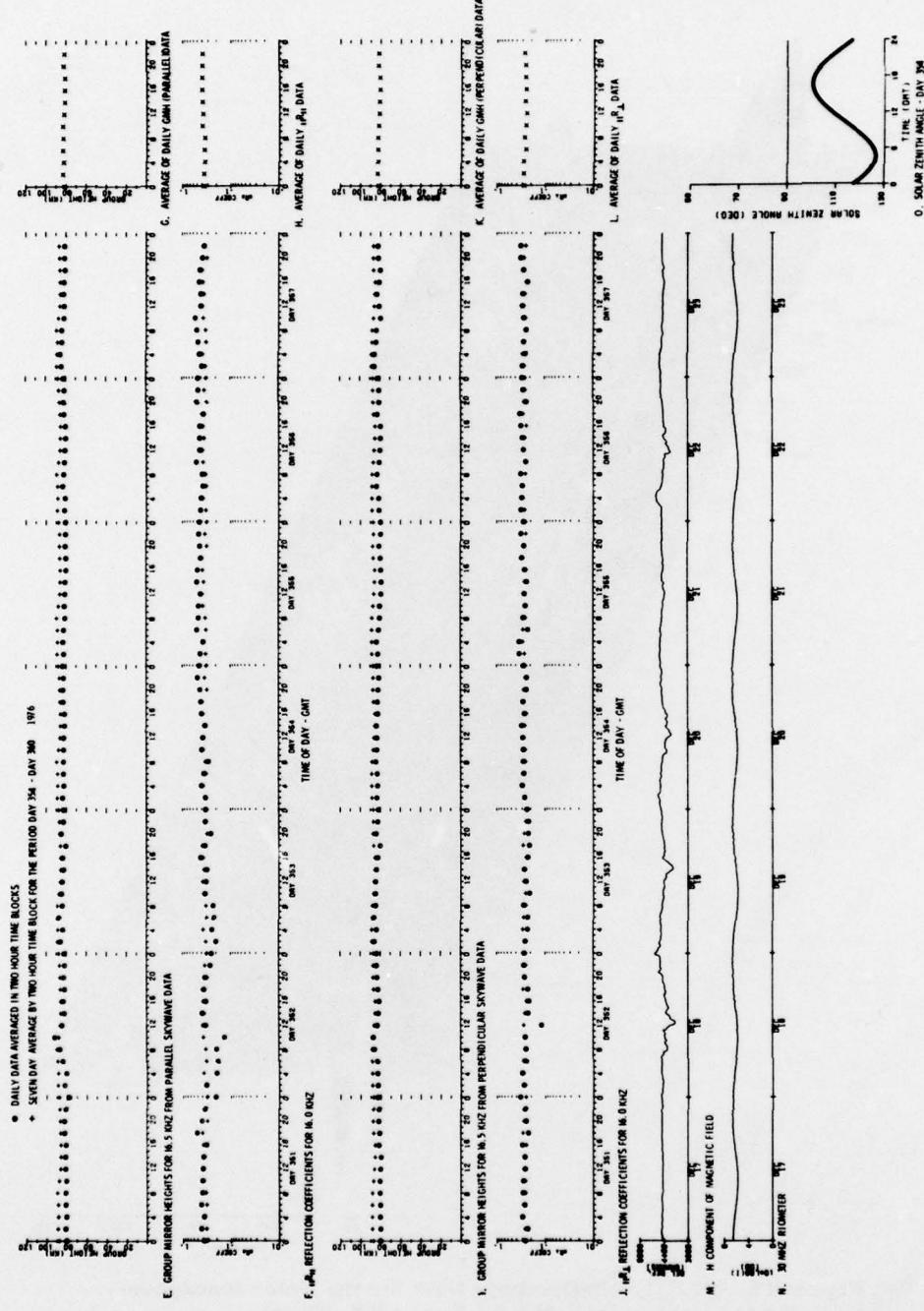


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 351 (17 Dec) - DAY 357 (23 Dec) 1978 (Cont)

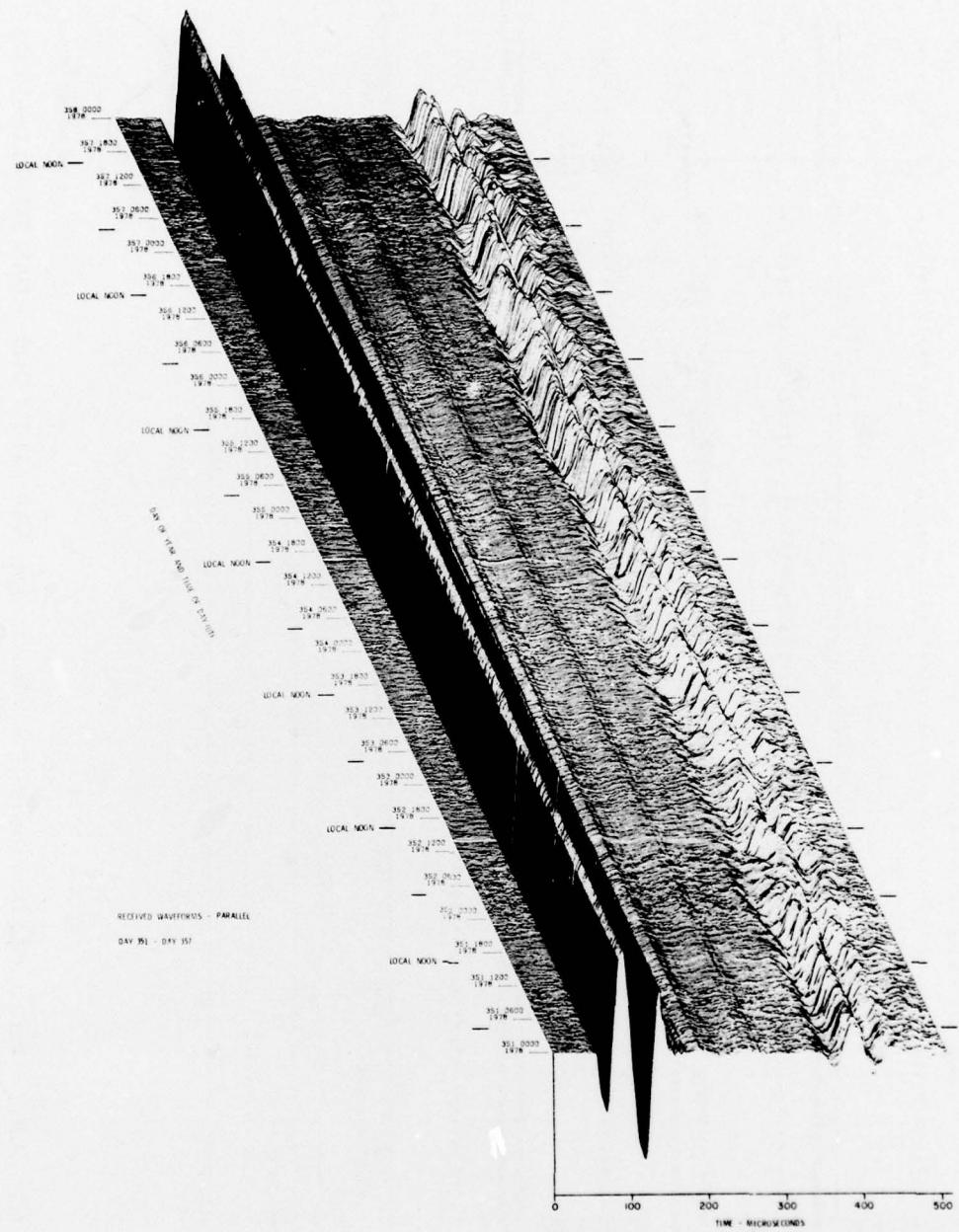


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 351 (17 Dec) — DAY 357 (23 Dec) 1978 (Cont)  
 Part R. II Waveform Display

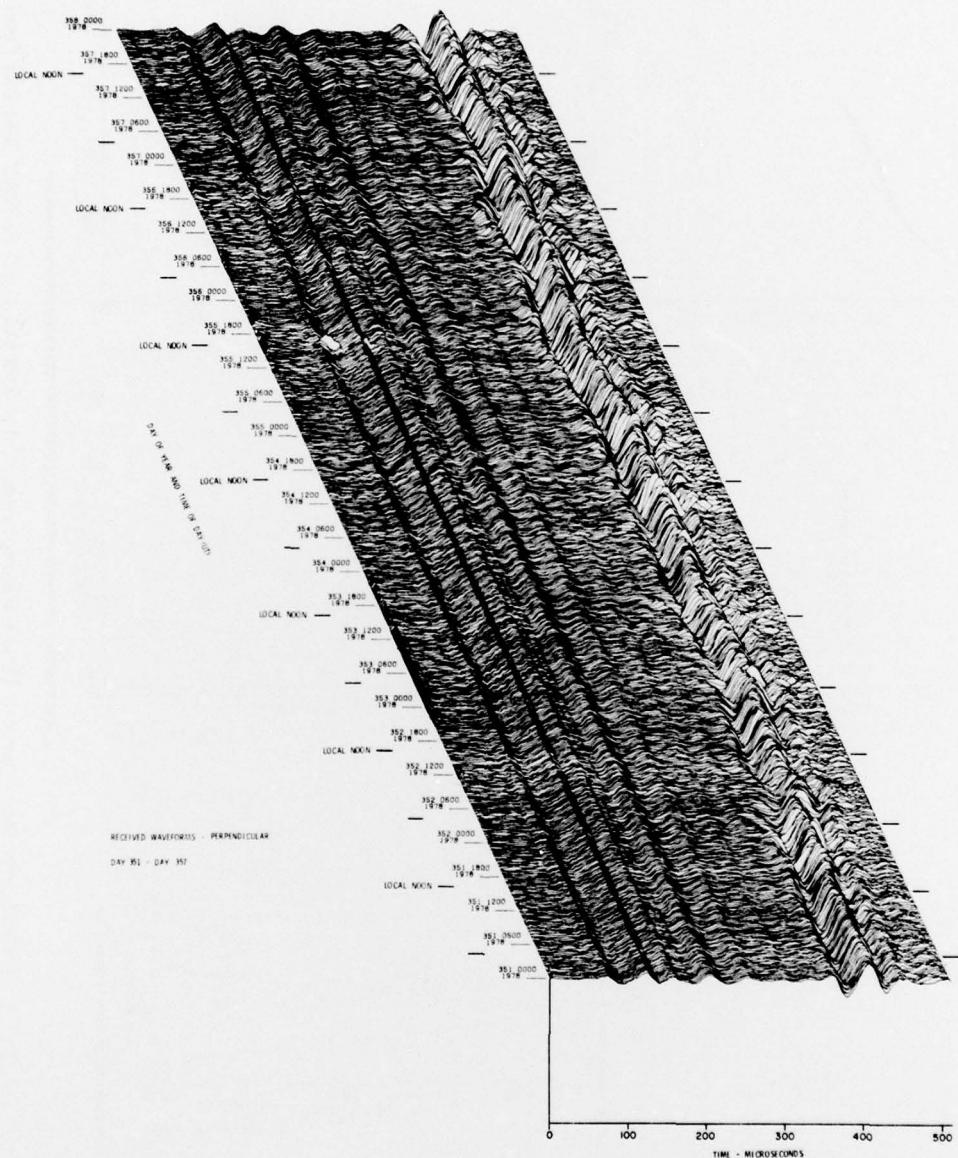


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 351 (17 Dec) — DAY 357 (23 Dec) 1978 (Cont)  
 Part S.  $\perp$  Waveform Display

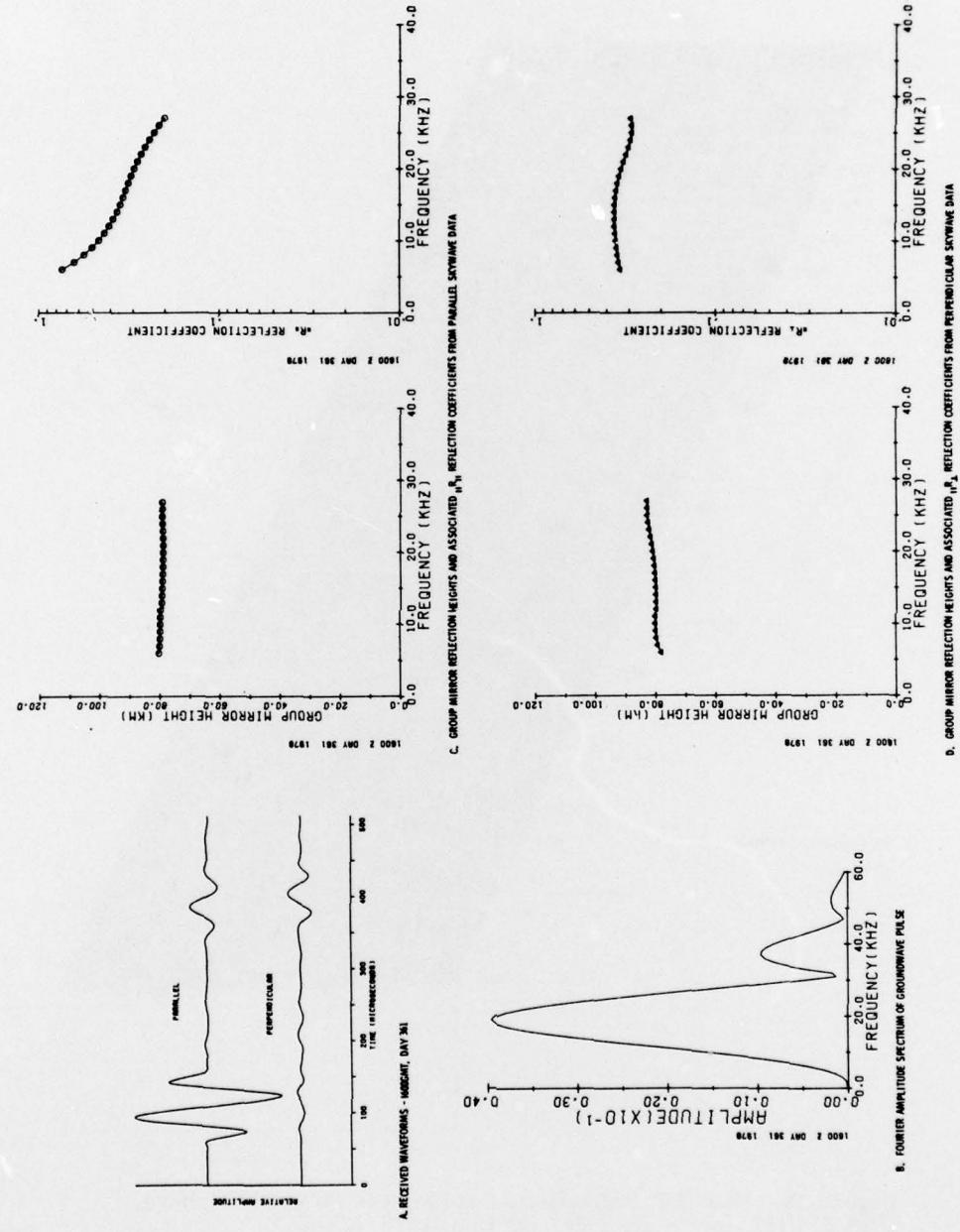


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 358 (24 Dec) – DAY 364 (30 Dec) 1978

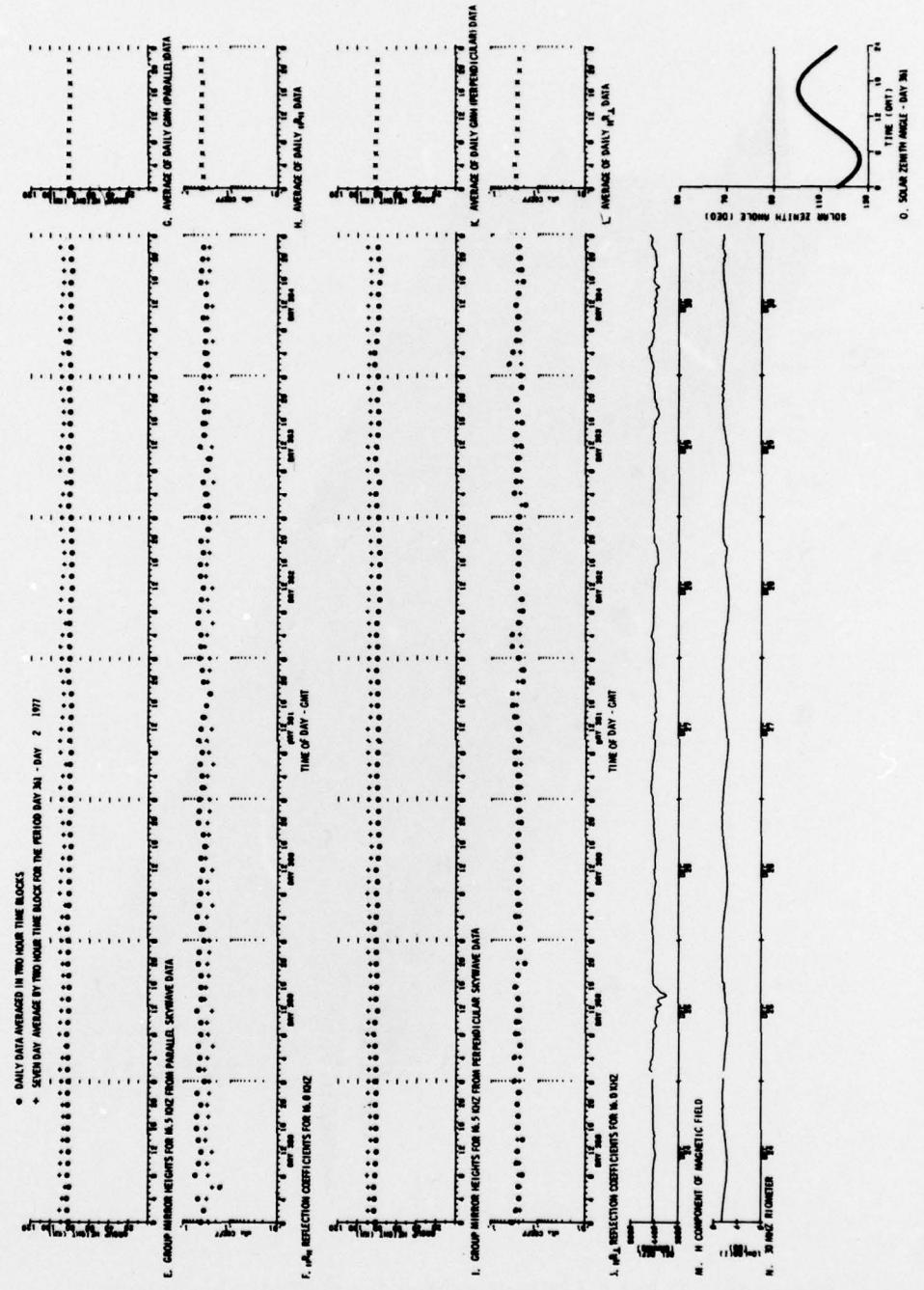


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 358 (24 Dec) – DAY 364 (30 Dec) 1978 (Cont)

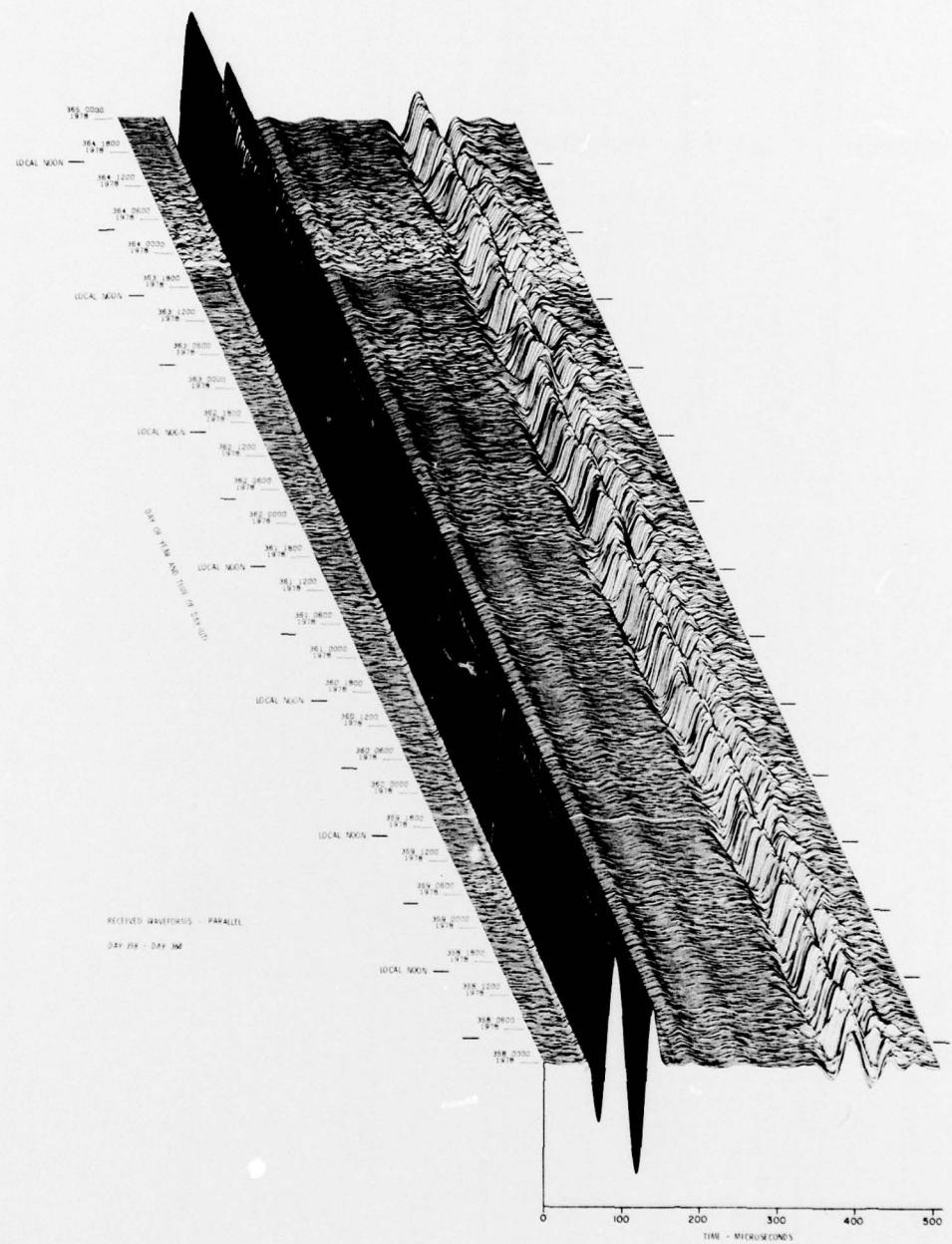


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 358 (24 Dec) - DAY 364 (30 Dec) 1978 (Cont)  
 Part R. II Waveform Display

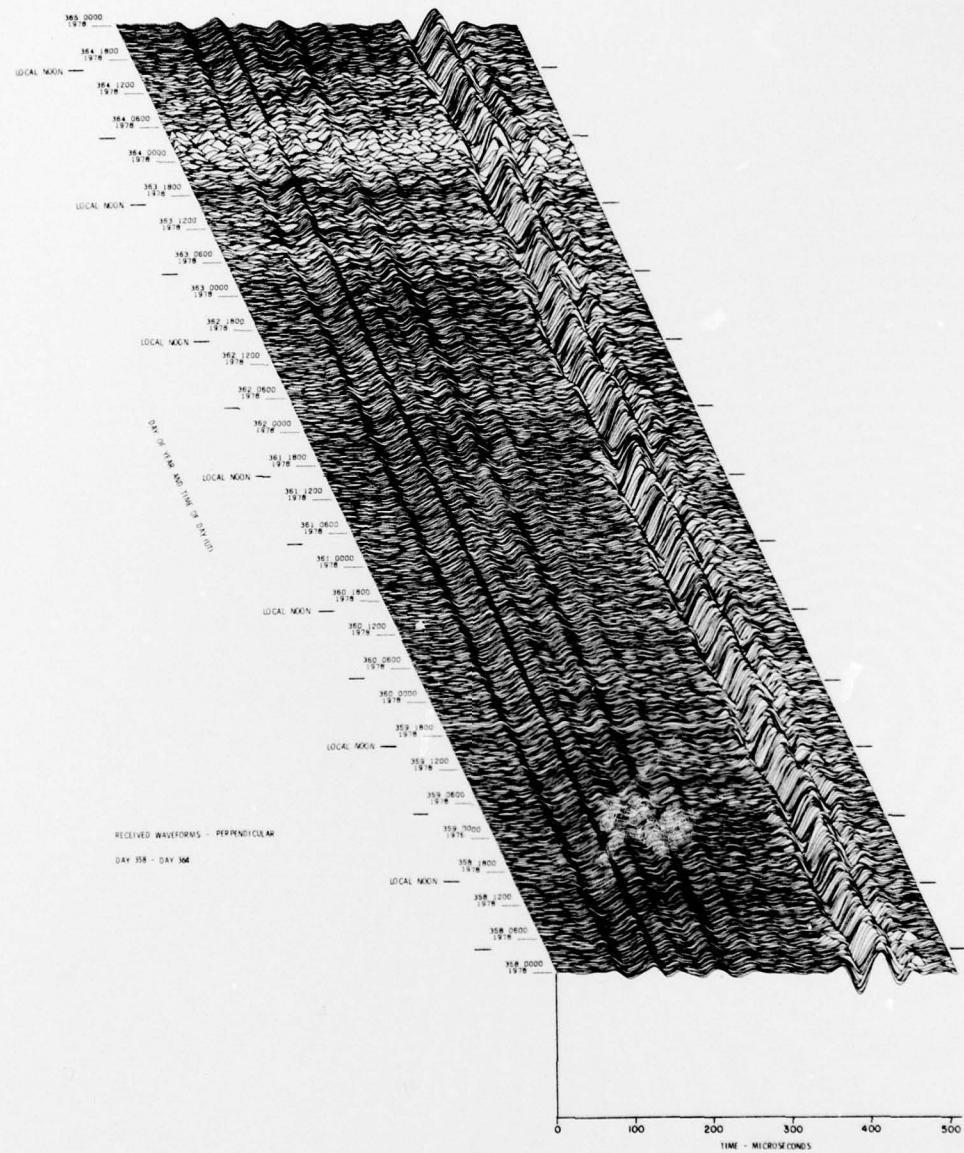


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere,  
 DAY 358 (24 Dec) — DAY 364 (30 Dec) 1978 (Cont)  
 Part S.  $\perp$  Waveform Display

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RADC plans and executes research, development, test and selected acquisition programs in support of Command, Control Communications and Intelligence (C<sup>3</sup>I) activities. Technical and engineering support within areas of technical competence is provided to ESD Program Offices (POs) and other ESD elements. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.